PALIS # 81122

LAKE SHIRLEY NUTRIENT LOADING/
DREDGING FEASIBILITY STUDY

Lake Shirley Nutrient Loading/ Dredging Feasibility Study

January 19, 2000

Prepared For:
The Lake Shirley Improvement Corporation
and
The Town of Lunenburg

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LAKE SHIRLEY
NUTRIENT LOADING / DREDGING FEASIBILITY STUDY

Table of Contents

Executive Summary....iii

1.0 Nutrient Loading Evaluation....1
- 1.1 Water Quality Sampling Program....1
- 1.2 Water Quality Sampling Results....5
- 1.3 GIS Land Use Analysis....23
- 1.4 Land Use Nutrient Export Model....26
- 1.5 Nutrient Loading Control Alternatives....34

2.0 Dredging Feasibility Evaluation....43
- 2.1 Review of Existing Data....43
- 2.2 Sediment Sampling Program....43
- 2.3 Dredging Method Analysis....50
- 2.4 Dredging Permitting Assessment....54

References....57

Appendices
- Appendix 1: Climate Data
- Appendix 2: Phosphorus Loading Model Data

List of Tables

Table 1-1: Water Chemistry Sampling Results – In-lake Sampling Stations....5
Table 1-2: Water Chemistry Sampling Results – Tributary Sites....6
Table 1-3: Average Dry and Wet Sampling TP Concentrations....12
Table 1-4: Lake Shirley Watershed Land Use Area Coverages....25
Table 1-5: DEP Simplified Land Use Classifications....28
Table 1-6: Lake Shirley Simplified Land Use Area Coverages....28
Table 1-7: Phosphorus Loading Model Results....29
Table 1-8: Selected Basin and Flood Characteristics for Gaged Stations....36
Table 1-9: TP removal Rates by Detention Time....38
Table 1-10: Catacoonamug Brook Storage for 6 Hours Holding Time....39
Table 1-11: Easter Brook Required Storage for 6 Hours Holding Time....39

Table 2-1: Sediment Analysis Parameters....45
Table 2-2: Sediment Boring Summary....45
Table 2-3: Sediment Physical Analysis Results....46
Table 2-4: Sediment Chemical Analysis Results....48
Table 2-5: Dredging Depth Analysis....50

List of Figures

Figure 1:	Lake Shirley Sub-Watersheds and Sampling Location	2
Figures 2a-2c:	Stations 1-3, Depth vs. Total Phosphorus	9
Figures 3a-3e:	Easter Brook Stations, Total Phosphorus	10
Figures 4a-4e:	Catacoonamug Brook Stations, Total Phosphorus	11
Figures 5a-5c:	Stations 1-3, Depth vs. Ammonia-Nitrogen	13
Figures 6a-6e:	Easter Brook Stations, Ammonia-Nitrogen	14
Figures 7a-7e:	Catacoonamug Brook Stations, Ammonia-Nitrogen	15
Figures 8a-8b:	Station 1, Depth vs. Temperature and DO	17
Figures 9a-9b:	Station 2, Depth vs. Temperature and DO	18
Figures 10a-10b:	Station 3, Depth vs. Temperature and DO (6/9/99)	19
Figure 11:	In-lake Sampling Station Clarity	21
Figure 12:	Lake Shirley Watershed Land Uses	24
Figure 13:	Symptoms of Eutrophication	26
Figure 14:	Estimated External Total Phosphorus Load by Sub-watershed	30
Figure 15:	Relative Total Phosphorus Load per acre for each Sub-watershed	30
Figure 16:	Estimated External TP Load for each Sub-watershed by Land Use	31
Figure 17:	Results of Settling Column Study on Urban Runoff	38
Figure 18:	Sediment Sampling Locations	44

EXECUTIVE SUMMARY

INTRODUCTION

The Lake Shirley Nutrient Loading/Dredging Feasibility Study was conducted by BSC Group, Inc. (BSC) for the Town of Lunenburg and the Lake Shirley Improvement Corporation (LSIC). Funding for this study was provided by the LSIC and a matching grant from the Massachusetts Department of Environmental Management-1999 Lakes and Ponds Grant Program.

Lake Shirley is a shallow, 354-acre reservoir located within the Nashua River watershed in Lunenburg and Shirley, Massachusetts. For the past several years, the LSIC has become increasingly concerned with a variety of lake management issues, including declining water quality, poor clarity, algae blooms, nuisance growth of aquatic plants, and sedimentation. In response to these concerns, the LSIC hired BSC to conduct this study. The first part of the study, the Nutrient Loading Evaluation, focused on assessing watershed sources of pollution to Lake Shirley. The objectives of this part of the study were to:

1. Provide updated data on in-lake and tributary water quality conditions;
2. Develop a model to estimate nutrient loading from Lake Shirley's subwatersheds;
3. Provide recommendations for nutrient-loading mitigation.

The second part of the study, the Dredging Feasibility Evaluation, focused on assessing the costs, benefits and feasibility of dredging Lake Shirley. The objectives of this part of the study were to:

1. Conduct a pre-dredge survey to confirm soft sediment depths and analyze sediment chemical properties and physical characteristics;
2. Evaluate permitting issues, dredge material disposal options, and dredging methods;
3. Assess the potential benefits and estimated costs of dredging.

NUTRIENT LOADING EVALUATION

Water Quality:

Sampling was conducted at in-lake and tributary locations. The unusually low amount of rainfall during the summer of 1999 resulted in low streamflow and stagnant in-lake conditions. As a result, it is difficult to directly compare the 1999 data with data collected in 1986 by Metcalf and Eddy (M&E). However, the data can be used to draw some general conclusions about Lake Shirley and its trend towards increasingly eutrophic conditions, including the following:

- Phosphorus is the most important nutrient for the growth of algae and aquatic plants in most lakes. In-lake levels of Total Phosphorus (TP) in July 1999 were significantly higher than in July 1986. Tributary TP levels were moderately higher in 1999, and consistently exceeded the levels required to support eutrophic in-lake conditions. At Catacoonamug Brook and Easter Brook, TP levels were similar and showed no significant variation between (1) wet and dry weather sampling or (2) upstream and downstream sampling locations.

- The vertical extent and severity of summer oxygen depletion at the south basin deep hole has increased significantly. These conditions indicate degraded fish habitat, increased seasonal nutrient recycling from sediments, and a general increase in the severity of eutrophication.

- As oxygen depletion at the deep-hole has increased, there has been an equally dramatic decline in hypolimnetic (deep water) pH levels during summer stratification.

- Water clarity has decreased significantly. In July 1999, the state standard for swimming beaches (4-foot clarity) was not met at any of the sampling stations. The decreased water clarity appears to be due to increased growth of algae, indicating advancing eutrophication.

Land-Use Nutrient Export Model:

Land uses within a watershed determine the amount of nutrient loading to a lake. For example, runoff from forested land is typically much lower in nutrient content than runoff from fertilized agricultural land. To estimate nutrient loading to Lake Shirley, BSC used a land-use export model developed by the Massachusetts Department of Environmental Protection. The model uses phosphorus export coefficients for land uses that are tailored to conditions in Massachusetts. The model was "calibrated" for Lake Shirley by using field data collected by BSC in 1999. The model was used to estimate total phosphorus loading from tributaries, direct surface runoff and septic systems. Results of the nutrient loading model are summarized below:

- Catacoonamug Brook contributes by far the most phosphorus to the lake (279.1 kg/year). Although this subwatershed provides 42.8% of the total TP load, it comprises 61% of the lake's watershed and has the second lowest per-acre contribution (0.051 kg/acre/year).

- Easter Brook has the second-highest total TP loading (125.9 kg/year). This subwatershed comprises 21% of the total watershed and 19.3% of the estimated total TP load.

- Sub-watershed E (Keating area) was calculated to have the highest per-acre TP loading rate (0.161 kg/acre/year), but contributed a relatively modest total TP load due to its small size.

- Although the lake's proximal watershed comprises only 10% of the total watershed, the combined TP load from surface runoff and septic systems is roughly 25% of the total load.

Nutrient Loading Control Alternatives:

To evaluate opportunities for nutrient loading reduction, BSC (1) conducted an assessment of stream flows and TP concentrations and (2) evaluated the feasibility and potential siting areas for best management practices (BMPs).

Because of the size of the Easter Brook and Catacoonamug Brook subwatersheds and the significant flows that come from them, stormwater detention methods are not feasible. Only major damming projects requiring large amounts of space are likely to achieve any effective phosphorus removal. Also, Easter Brook and Catacoonamug Brook have extensive wetland systems that provide significant flood storage and nutrient uptake. The incremental benefits provided by additional engineered detention capacity would be relatively minor.

An alum-injection system could potentially be sited near the Easter Brook inlet or Catacoonamug inlet to Lake Shirley. These systems are used to reduce soluble phosphorus levels from stream water by dosing stream flows with liquid alum. Alum permanently binds with phosphorus, making it unavailable for biological uptake by algae. This type of treatment, which is commonly used to process drinking water, has been used to successfully reduce nutrient loading from streams where other BMPs were not feasible. Depending on flow rates and in-stream nutrient levels, phosphorus removal rates of 50-90% have been reported with this type of treatment. An alum injection system would cost approximately $75,000, with anticipated annual maintenance and supply costs estimated at approximately $5,000 per year.

Nutrient source reduction techniques generally apply to all parts of the Lake Shirley watershed, but will be relatively more effective in areas closest to the lake. Several options for source reduction are summarized below:

- Septic system testing: $200 to $250 per home, or $45,000 to $55,000 for all 224 homes adjacent to the lake.

- Enhance existing street drainage: $2,000 for each new drain manhole

- Replace existing catch basins with deep sumps (minimum 4-foot deep) and hooded outlets: $3,000 per catchbasin. Although less effective, existing catchbasins may be retrofitted with hooded outlets for $300 each.

- Vacuum-clean catchbasins at least once per year.

- Improve treatment effectiveness of existing roadside ditches by excavating to increase cross section. Loam and seed can then be placed with check dams to make the ditch function as a vegetated water quality treatment swale. Cost will vary, depending on land purchase/easements required.

- All new developments in the Lake Shirley watershed should be required to meet the state Stormwater Management Policy standards. Local regulations under the Subdivision Control Law would require modification to incorporate these standards.

- Cluster or Planned Unit Development zoning bylaws should be emphasized. Local Conservation bylaws that restrict development in the buffer zone to wetlands can provide protection by siting potential pollutants further from streams, wetlands and the lake.

- Agricultural BMPs: vegetated buffer strips, interception swales

<u>DREDGING FEASIBILITY EVALUATION</u>

Sediment Sampling:

A pre-dredge sediment survey was conducted to (1) obtain information on sediment chemical and physical properties and (2) measure soft sediment depths at key locations. An analysis of the sediment survey is summarized below:

- The levels of all metals, PAHs and PCBs tested low enough to fall within Category One, the cleanest classification of dredged material under Massachusetts regulations. This classification allows for the widest range of upland disposal and re-use options. The level of Total Petroleum Hydrocarbons was within the acceptable range for disposal at lined landfills, but high enough to trigger the need for additional testing if beneficial upland re-use is proposed.

- The soft sediment layer at the sampling stations can be characterized as having several feet of extremely flocculent muck/silt, overlying a more consolidated peat layer. Sediment grain size analysis indicates that Lake Shirley sediments are comprised primarily of extremely fine, silty organic material. Sediment processing is likely to be required in order to make dredged material from the lake suitable for most upland disposal options. Most potential uses, including use as daily cover at landfills, or as topsoil for agriculture or sporting fields, would require mixing with a more coarse material (sand) to improve structure.

- Soft sediment depths at the sampling stations ranged from four to nine feet. Although the sediment depths measured by BSC were generally several feet deeper than those measured by M&E in 1986, the variation is largely attributed to differences in methodology, rather than a significant accumulation of soft sediment since 1986.

Dredging Analysis:

The feasibility of dredging Lake Shirley was assessed in response to water quality degradation related to nuisance growth of macrophytes and algae. To control macrophyte growth, dredging must either (1) excavate to a depth which limits sunlight penetration to the sediments, or (2) remove soft, organic sediments and excavate down to an inorganic layer (e.g. sand, gravel) that provides a less suitable substrate for plant growth. An analysis of dredging Lake Shirley for macrophyte control is summarized below:

- Depths of at least 10 feet of water are necessary before light would become limiting for plant growth. Roughly 84% of Lake Shirley is less than 10 feet deep. However, 34% of the lake is between 8 and 10 feet deep, which means that light limitation could be achieved in these areas by dredging the first two feet of sediment. This amount of dredging would result in 50% of the lake (177 acres) having a depth of 10 feet or greater. After the first two feet, the cost effectiveness of dredging to light limiting depths declines dramatically.

- The volume of sediment removal required to reach an inorganic substrate over 50% of the lake is much greater than the volume of removal required to achieve light-limiting depths over 50% of the lake.

Dredging can also be used to remove nutrient-rich sediments that lead to algal blooms. An analysis of dredging Lake Shirley for algae control is summarized below:

- In deep lakes, summer thermal stratification can cause oxygen depletion in the hypolimnion (deep waters). This causes phosphorus from sediments to be re-released into the water, fueling the growth of algae. However, Lake Shirley is relatively shallow reservoir which does not experience significant summer stratification. Therefore, design of a dredging program for Lake Shirley should not focus on seasonal sediment nutrient recycling.

- In shallow lakes with flocculent bottom sediments, such as Lake Shirley, the resuspension of sediments due to disturbances such as motor boats and strong winds can contribute to algal blooms. Almost the entire lake is less than 15 feet deep, shallow enough for a 50-horsepwer boat to cause sediment resuspension. Dredging could improve water clarity and nuisance algae growth by removing the flocculent top-layer sediments most prone to resuspension.

Based on the above discussion of plant and algae control objectives, a target removal *of no less than* two feet of sediment over 70% of the lake area (248 acres) is recommended, for a *minimum* total removal of 807,000 cubic yards. Dredging to greater depths would provide a greater area of plant control and improve the longevity of control, but these advantages must be weighed against project costs and anticipated funding constraints.

Dredging Method:

Because Lake Shirley is an impoundment with a dam that allows for drawdown, both conventional (dry) dredging and hydraulic (wet) dredging are possible and were assessed. Dry dredging involves draining the lake and removing sediments with conventional excavation techniques and equipment. Hydraulic dredging involved specialized floating equipment that pump sediments from the lake in a wet slurry form.

The feasibility of dry dredging Lake Shirley is summarized as follows:

- Due to capacity limitations of conventional excavation equipment, dry dredging is most feasible for of small reservoirs with 30,000 cubic yards or less to be removed. A tremendous amount of truck traffic, totaling over 60,000 trips, would be required to remove the minimum recommended volume of sediment from Lake Shirley (807,000 cubic yards).

- A continuous dredging operation for 128 days each year during the winter (allowing the lake to refill in the summer) would take six years to complete. A variety of logistical considerations could easily extend the length of the project by several years.

- Dry dredging requires draining the lake, and an assessment of potential impacts to private wells would be required. If the water supply to a substantial number of homes will be impacted, the cost of providing an alternative water supply could be prohibitive.

Hydraulic dredging is the method most commonly used for the removal of large volumes of sediment. The feasibility of hydraulically dredging Lake Shirley is summarized as follows:

- Most hydraulic dredges are designed to remove sand, silt or clay, and are less efficient at removing the highly flocculent sediments found at Lake Shirley. This would likely result in a slurry with a high water content, requiring a relatively large area for containment/dewatering.

- Siting a dewatering area poses a major obstacle, since private homes surround most of the lakeshore. Several active and inactive gravel pits in the area could potentially be used for dewatering. However, none of these sites are adjacent to the lake, increasing both the cost and difficulty of transporting the slurry and disposing of the water.

- Sediment disposal is likely to be very difficult and expensive. Few landfills could accept the large volume of sediment proposed for removal. Even if a disposal area is located, disposal costs are likely to range from $2 to $4 per cubic yard. Additional testing for Total Petroleum Hydrocarbons will be required before beneficial upland re-use of sediments can be proposed.

Overall, the financial and logistical constraints to dredging Lake Shirley are very high. To hydraulically dredge 807,000 cubic yards would cost an estimated $7 to $9 million dollars.

Dredging Permitting:

Dredging is a complicated process with a potential for significant environmental impacts. As such, a dredging project at Lake Shirley would require an extensive permitting process involving local, state and federal permits and approvals. The most expensive permitting effort required would be review under the Massachusetts Environmental Policy Act (MEPA), which could cost from $50,000 to $250,000.

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Dredging Permitting:

Dredging is a complicated process with a potential for significant environmental impacts. As such, a dredging project at Lake Shirley would require an extensive permitting process involving local, state and federal permits and approvals. The most expensive permitting effort required would be review under the Massachusetts Environmental Policy Act (MEPA), which could cost from $50,000 to $250,000.

1.0 NUTRIENT LOADING EVALUATION

1.1 Water Quality Sampling Program

After reviewing existing data sources, including the Diagnostic/Feasibility Study of Lake Shirley (Metcalf & Eddy, 1988) and United States Geologic Survey (USGS) quadrangle maps of the Lake Shirley watershed and sub-watershed areas, water quality sampling stations were selected at in-lake locations and along the major tributaries and inlets which flow to Lake Shirley.

<u>Sampling Stations</u>

A total of 14 investigative sampling stations were located within the Lake Shirley watershed. This allowed for data collection and nutrient loading quantification for each of the 6 sub-watersheds. Sampling was also conducted at three in-lake locations. The location of the sampling stations is given in Figure 1 and a brief description of each site is as follows:

Easter Brook sub-watershed (Area A): Dry and wet weather nutrient sampling was conducted at five locations within the 1,943 acre Easter Brook sub-watershed, referred to as Area A. Several other locations were investigated as potential sampling stations, but had either no flow or insufficient flow for sample collection on the sampling dates. The Area A sampling stations can be described as follows:

- A-1: Located at the Easter Brook inlet to Lake Shirley. Samples were taken east of Reservoir Road, off property owned by Shady Point Campground.

- A-2: Located where Easter Brook crosses under Goodrich Road.

- A-3: Located where Easter Brook crosses under Lancaster Avenue. Samples were taken on the west side of the road, just downstream of the confluence of Easter Brook and an unnamed tributary.

- A-4: Located where an unnamed tributary to Easter Brook crosses under Lancaster Avenue, just east of the intersection of Lancaster Avenue and Prospect Street.

- A-5: Located where Easter Brook crosses under Pierce Street, northeast of a small pond which forms the headwaters of Easter Brook.

Catacoonamug Brook sub-watershed (Area B): Dry and wet weather nutrient sampling was conducted at five locations within the 5,549 acre Catacoonamug Brook sub-watershed, referred to as Area B. Several other locations were investigated as potential sampling stations, but had either no flow or insufficient flow for sample collection on the sampling dates. The Catacoonamug Brook watershed sampling stations can be described as follows:

- B-1: Located at the Catacoonamug Brook inlet to Lake Shirley, samples were taken just north of the Flat Hill Road bridge.

- B-2: Located where Catacoonamug Brook crosses under Reservoir Road, just north of the intersection of Reservoir Road and Flat Hill Road.

- B-3: Located where the unnamed stream exiting Massapoag Pond crosses under Goodrich Road.

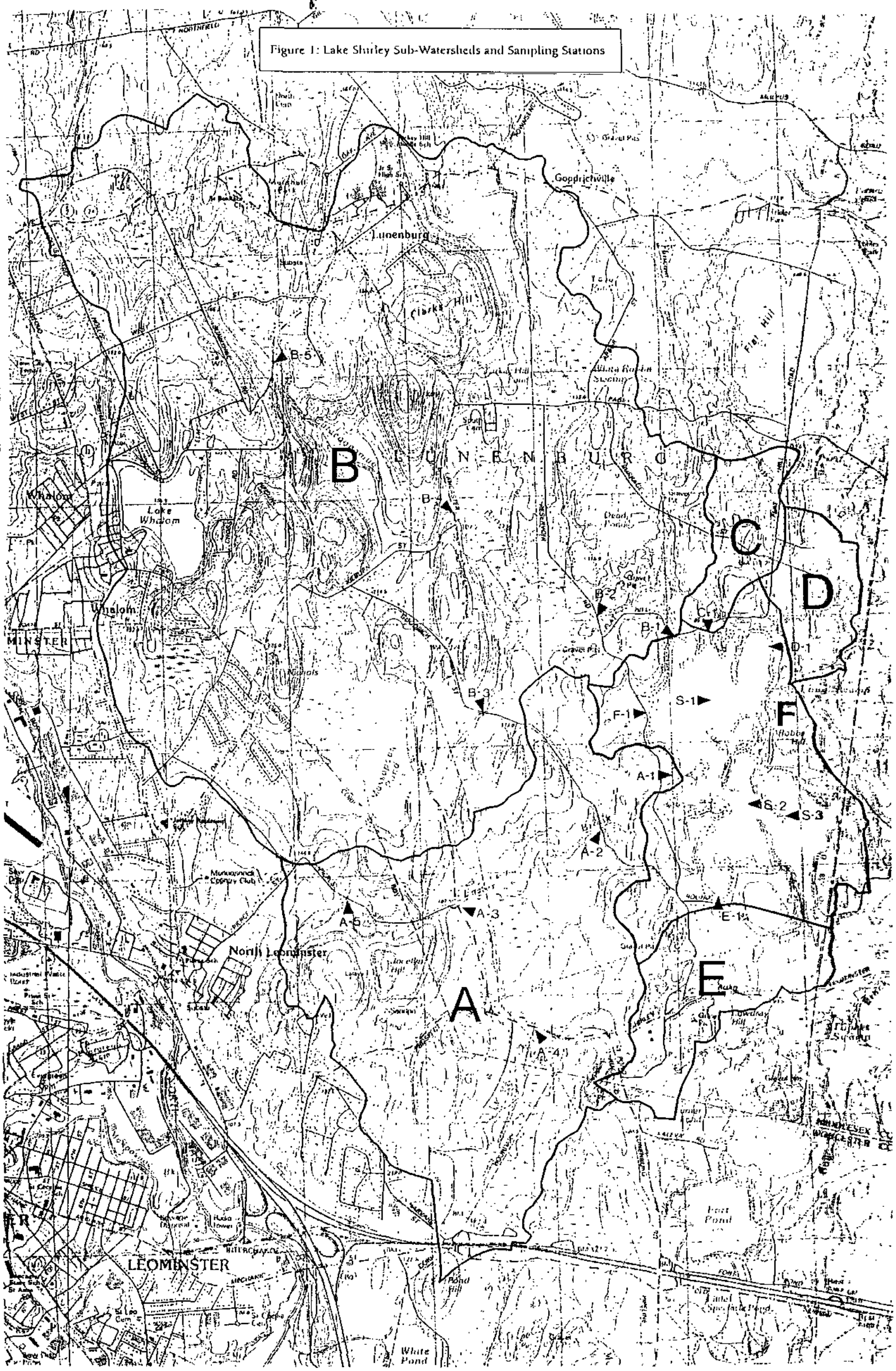


Figure 1: Lake Shirley Sub-Watersheds and Sampling Stations
Lunenburg
Goodrichville
Clarks Hill
Flat Hill
Lake Whalom
Whalom
B
C
D
F
E
A
B-5
B-4
B-3
B-2
B-1
F-1
S-1
S-2
S-3
D-1
A-1
A-2
A-3
A-4
A-5
E-1
North Leominster
LEOMINSTER
Dead Pond
Fort Pond
White Pond
Monoosnock Country Club

- B-4: Located where Catacoonamug Brook crosses under Lancaster Avenue, just north of the intersection of Lancaster Avenue and Kilburn Street.

- B-5: Located where Catacoonamug Brook crosses under Day Street, north of the intersection of Day Street and Sunnyhill Road.

Other Sub-watersheds:

- C-1: Located at a culvert to the south of Flat Hill Road, this station was selected to capture runoff from the Area C, a small (170 acres) sub-watershed to the north of Lake Shirley. Area C is primarily forested, and includes some residential development along Burrage Street and Flat Hill Road. During all four sampling events, this station had no water flow.

- D-1: Located where a culvert drains towards Lake Shirley on the west side of Sunset Road. This station captures runoff from Area D (196-acres), a primarily forested sub-watershed.

- E-1: Located just north of Round Street at the southern end of the lake, this station was selected to capture runoff from sub-watershed Area E (392 acres).

- F-1: Located just east of Reservoir Road, where a wetland to the west of the northern basin flows toward Lake Shirley via a culvert. This station captures runoff from a portion of Area F, the majority of which is the proximal watershed which drains directly to the lake via overland flow.

In-Lake Sampling Stations:

Water quality sampling was conducted at three in-lake stations during the summer to evaluate conditions (1) during the height of the growing season, and (2) when the water column at deepest portions of the lake would exhibit summer stratification.

- S-1: Located at the deep hole of the shallow northern basin.

- S-2: Located to the east of the narrow channel separating the northern basin from the middle section of the lake.

- S-3: Located at the deep hole of the southern basin.

<u>Sampling Methodology</u>

A water quality sampling program was developed to evaluate overall in-lake conditions and nutrient loading inputs from the Lake Shirley sub-watersheds. Tributary sampling efforts were focused on the Easter Brook and Catacoonamug Brook sub-watersheds, which together contribute over 90% of the surface water runoff to Lake Shirley. The tributary stations were sampled twice during dry weather (June 6 and July 30, 1999) and twice during wet weather (July 1st and September 10th, 1999). The total rainfall recorded from the two wet weather sampling events, as recorded at the National Weather Service precipitation monitoring station in Fitchburg, was 0.11 inches on July 1 and 3.13 inches on September 10. BSC feels that the July 1 precipitation data from Fitchburg underestimates the actual amount of rainfall in the Lake Shirley watershed. Persistent rainfall, quite heavy at times, continued for at least three hours preceding and during the time of sample collection on July1. The recorded precipitation totals from this storm varied considerably from town to town, with 1.44 inches in Worcester, 0.04 in Orange, .64 inches in Taunton and 0.25 inches in Bedford.

Sample collection at individual stations was dependent upon sufficient flows.

Surface grab samples were taken at all tributary sampling stations. To measure total phosphorus and ammonia-nitrogen concentrations, water samples were collected, put on ice, and transported to Microbac Laboratories, Inc., (Clinton, MA) for laboratory analysis. All data and samples were collected using EPA protocols for the parameter under investigation. Analysis was conducted according to EPA protocols.

The in-lake stations were sampled twice (June 6th and July 30th, 1999). A Hydrolab Datasonde 4 was used to conduct *in-situ* measurements of pH, specific conductivity, dissolved oxygen (DO), and temperature. During the in-lake sampling, Hydrolab measurements were also obtained at the two major tributary inlet stations, Easter Brook inlet (station A-1) and Catacoonamug Brook inlet (station B-1). Insufficient flow or lack of flow prevented Hydrolab measurements from the other lake inlets on these sampling days. Water quality measurements were recorded at just below the lake surface and at one-meter intervals within the water column until the lake bottom was reached. Water clarity, as measured by Secchi disk depth, was also measured at the in-lake stations.

To measure total phosphorus and ammonia-nitrogen, surface grab samples were taken at all in-lake stations. Additional grab samples were taken with a Kemmerer sampler from the center and at the bottom of the water column.

1.2 Water Quality Sampling Results

Water quality sampling results from the in-lake stations are given in Table 1-1, and results from the tributary stations are given in Table 1-2. A description of each water quality parameter and an analysis of the results are summarized below. The near-drought conditions and unusually low water table that existed during the summer of 1999 prohibited tributary sample collection at some stations due to insufficient flow or complete lack of flow (Refer to Appendix 1 for Climate Data). The relatively low streamflow conditions and stagnant in-lake conditions in 1999 also make it difficult to directly compare this water quality data to the data collected by M&E in 1986. However, the tributary water quality data that was collected can be used to draw some general conclusions which are useful to this study.

Table 1-1: Water Chemistry Sampling Results - In-Lake Sampling Stations

Station	Date	Depth (m)	Temp (°C)	DO (mg/l)	pH (S.U.)	Spec. Cond (mS/cm)	TP (mg/l)	Ammonia-N (mg/l)	Clarity (Secchi)	Notes
S-1	6/9/99	0.0	25.0	6.2	7.3	0.206	<0.01	<0.2	5.8 Feet	100% cloudy
		0.5	25.0	6.1	7.3	0.205	-	-		
		1.0	25.0	5.9	7.3	0.206	-	-		
		1.5	25.0	5.7	7.3	0.206	<0.01	<0.2		
		2.0	25.0	5.7	7.1	0.206	-	-		
		2.3	24.7	3.1	6.9	0.208	0.04	<0.2		
S-1	7/30/99	0.0	29.4	7.5	7.7	0.216	0.03	<0.2	3.8 Feet	Hazy, 75% cloudy
		0.5	29.4	7.8	7.7	0.216	-	-		
		1.0	28.9	7.9	7.7	0.216	-	-		
		1.5	27.6	7.3	7.0	0.215	0.04	<0.2		
		2.0	27.4	6.0	6.7	0.216	-	-		
		2.3	27.3	5.1	6.5	0.218	0.06	<0.2		
S-2	6/9/99	0.0	25.1	6.4	7.5	0.211	<0.01	<0.2	5.0 Feet	100% cloudy
		0.5	25.0	6.5	7.5	0.211	-	-		
		1.0	25.0	6.3	7.4	0.210	-	-		
		1.5	25.0	6.4	7.4	0.211	-	-		
		2.0	24.5	4.3	7.0	0.208	-	-		
		2.5	23.0	0.9	6.7	0.211	<0.01	<0.2		
S-2	7/30/99	0.0	30.4	7.4	8.2	0.222	0.03	<0.2	3.8 Feet	Hazy, 75% cloudy
		0.5	30.2	7.3	8.1	0.222	-	-		
		1.0	29.4	7.5	8.1	0.223	-	-		
		1.5	29.0	7.5	7.9	0.222	-	-		
		2.0	27.6	6.7	7.4	0.221	0.04	<0.2		
S-3	6/9/99	0.0	25.1	6.2	7.6	0.219	0.03	<0.2	5.5 Feet	100% cloudy
		1.0	25.1	5.8	7.6	0.209	-	-		
		2.0	25.1	5.8	7.5	0.215	-	-		
		3.0	22.3	0.9	6.7	0.216	-	-		
		4.0	17.7	0.1	6.0	0.209	-	-		
		5.0	14.8	0.1	5.4	0.209	0.03	0.3		
		6.0	12.6	0.1	4.9	0.209	-	-		
		7.0	11.1	0.1	4.5	0.212	-	-		
		8.0	9.9	0.1	4.3	0.215	-	-		
		9.0	9.5	0.1	4.3	0.217	-	-		
		10.0	9.4	0.1	4.2	0.218	0.04	<0.2		
		11.0	9.3	0.1	4.3	0.218	-	-		
		11.5	9.7	0.1	4.3	0.268	-	-		
S-3	7/30/99	0.0	29.3	7.4	8.5	0.219	0.03	<0.2	3.8 Feet	Hazy, 50% cloudy
		1.0	29.3	7.3	8.0	0.220	-	-		
		2.0	27.9	6.6	7.4	0.219	-	-		
		3.0	26.2	0.3	6.6	0.222	-	-		
		4.0	22.0	0.2	6.2	0.219	-	-		
		5.0	16.7	0.3	5.5	0.214	0.04	<0.2		
		6.0	13.2	0.4	5.2	0.226	-	-		
		7.0	11.3	0.3	4.2	0.230	-	-		
		8.0	10.1	0.4	3.9	0.230	-	-		
		9.0	9.8	0.5	3.9	0.233	-	-		
		10.0	9.8	0.6	4.3	0.233	0.13	3.0		Abnormaly high Ammonia-N conc.
A-1	6/9/99	0.0	19.3	6.9	7.2	0.299	0.03	<0.2		
	7/30/99	0.0	23.7	6.7	7.4	0.252	0.04	<0.2		
B-1	6/9/99	0.0	21.8	4.5	6.7	0.195	0.04	<0.2		
	7/30/99	0.0	27.1	5.5	6.7	0.160	0.26	0.30		

Table 1-2: Water Chemistry Sampling Results - Tributary Stations (page 1 of 2)

Station	Date	Sample Type	TP (mg/l)	Ammonia-N (mg/l)	Notes
A-1	6/9/99	Dry	0.03	<0.2	
	7/1/99	Wet	0.05	<0.2	
	7/30/99	Dry	0.04	<0.2	
	9/10/99	Wet	0.03	<0.2	
A-2	6/9/99	Dry	0.04	0.5	
	7/1/99	Wet	0.04	<0.2	
	7/30/99	Dry	0.06	0.3	
	9/10/99	Wet	0.08	0.3	
A-3	6/9/99	Dry	0.02	0.3	
	7/1/99	Wet	0.03	<0.2	
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	0.07	<0.2	
A-4	6/9/99	Dry	<0.01	0.2	
	7/1/99	Wet	0.08	<0.2	
	7/30/99	Dry	<0.01	<0.2	
	9/10/99	Wet	0.06	<0.2	
A-5	6/9/99	Dry	-	-	No Flow
	7/1/99	Wet	-	-	No Flow
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	0.14	0.2	
B-1	6/9/99	Dry	0.04	<0.2	
	7/1/99	Wet	0.04	<0.2	
	7/30/99	Dry	0.26	0.3	Abnormally high TP & N conc.
	9/10/99	Wet	0.02	<0.2	
B-2	6/9/99	Dry	0.08	0.2	
	7/1/99	Wet	0.07	<0.2	
	7/30/99	Dry	0.04	<0.2	
	9/10/99	Wet	0.06	<0.2	
B-3	6/9/99	Dry	-	-	No Flow
	7/1/99	Wet	0.4	2.1	Abnormally high TP & N conc.
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	0.03	<0.2	Lots of suspended solids
B-4	6/9/99	Dry	0.03	<0.2	
	7/1/99	Wet	0.04	<0.2	
	7/30/99	Dry	0.08	0.7	
	9/10/99	Wet	0.05	0.4	
B-5	6/9/99	Dry	0.09	0.3	
	7/1/99	Wet	0.06	<0.2	
	7/30/99	Dry	0.11	1.0	
	9/10/99	Wet	0.06	0.4	
C-1	6/9/99	Dry	-	-	No Flow
	7/1/99	Wet	-	-	No Flow
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	-	-	No Flow

Table 1-2 (cont.): Water Chemistry Sampling Results - Tributary Stations (page 2 of 2)

Station	Date	Sample Type	TP (mg/l)	Ammonia-N (mg/l)	Notes
D-1	6/9/99	Dry	-	-	No Flow
	7/1/99	Wet	0.06	<0.2	
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	0.01	<0.2	
E-1	6/9/99	Dry	-	-	No Flow
	7/1/99	Wet	-	-	No Flow
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	0.10	<0.2	
F-1	6/9/99	Dry	-	-	No Flow
	7/1/99	Wet	0.04	<0.2	
	7/30/99	Dry	-	-	No Flow
	9/10/99	Wet	0.08	0.3	

Total Phosphorus (TP)

Total Phosphorus (TP) is a measure of all of the organic and inorganic phosphorus forms present in the water. In freshwater lakes, phosphorous is usually the most important nutrient determining the growth of algae and aquatic plants. Because phosphorus is typically relatively less abundant than nitrogen, it is considered the "limiting" nutrient for biological productivity. In-lake TP concentrations greater than 0.025 mg/l are considered an indicator of eutrophic (nutrient-enriched) conditions.

In-lake Results: Figures 2a-c illustrate the depth vs. TP concentrations. TP concentrations at S-1 and S-2 were similar on both sampling dates. On the June 6, 1999 sampling, only the lake bottom reading from S-1 exceeded the minimum detection limit of 0.01 mg/l. Higher TP concentrations, indicative of eutrophic conditions, were measured on July 30, 1999. The TP concentration at station S-1 ranged from 0.03 mg/l to 0.06 mg/l. TP at S-2 ranged from 0.03 mg/l to 0.04 mg/l.

TP concentrations on both sampling dates were highest at the S-3 deep hole station, where measurements ranged from 0.03 mg/l at the surface to 0.13 mg/l at lake bottom. Higher TP concentrations at the lake bottom are attributed to biological decomposition and chemical reactions taking place at the sediment/water interface.

A comparison of data from July 22, 1986 (M&E) to data from July 30, 1999 indicates a dramatic increase in in-lake TP concentrations. In July 1986, the entire water column at both S-1 and S-3 was beneath the minimum detection limit of 0.01 mg/l. In 1999, as stated above, the entire water column at both stations was well above the TP concentration required to support eutrophic conditions, including abundant growth of algae and aquatic plants.

Tributary Results: Figures 3a-e illustrate the Easter Brook TP sampling concentrations. Figures 4a-e illustrate the Catacoonamug Brook TP sampling concentrations. Table 1-3 presents the average of the dry and wet sampling TP concentration results and a summary of conditions in 1986 for comparison.

The average base flow (dry weather) TP concentrations at the major lake inlets, Site A-1 (Easter Brook) and B-1 (Catacoonamug Brook), were 0.035 mg/l and 0.04 mg/l, respectively. These results did not vary dramatically from the average wet weather TP concentrations, which were 0.04 mg/l and 0.03 mg/l, respectively. While the TP concentrations at the other lake inlet stations varied by sampling location and by sampling date, the overall TP concentrations from the Easter Brook and Catacoonamug Brook inlets were relatively similar and consistent. TP concentrations from these two inlets have the greatest impact on the total external nutrient load to Lake Shirley, since their combined flow accounts for approximately 91% of the total inflow into the lake (M&E, 1988).

Along the upstream reaches of both Easter Brook and Catacoonamug Brook, the average TP concentrations varied by sampling location and by sampling date (dry vs. wet). Many of the water quality sampling results showed TP concentrations that were greater than the 0.025 mg/l eutrophication benchmark.

Figure 2a: Station 1(S-1)
Depth vs. Total Phosphorus (TP) Concentration

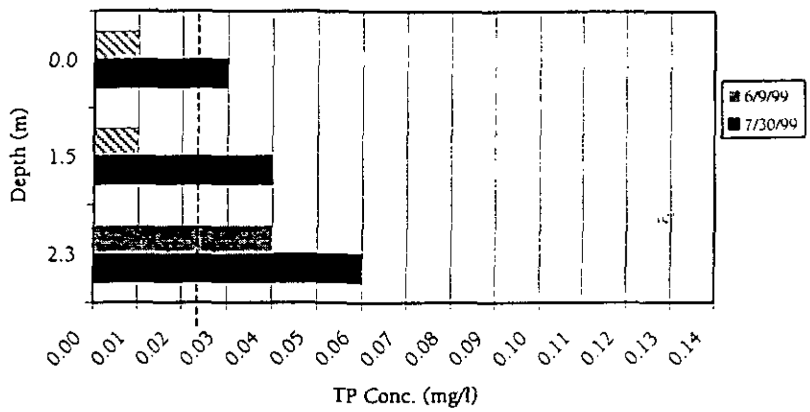
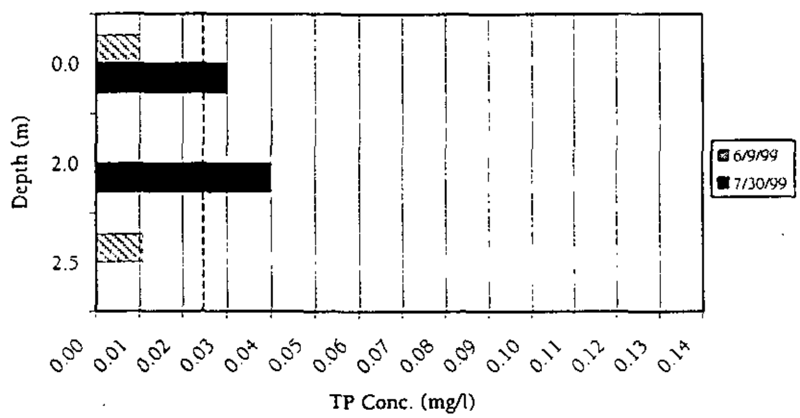


Figure 2b: Station 2 (S-2)
Depth vs. Total Phosphorus (TP) Concentration



Note: Columns with the striped fill pattern indicate concentration results less than test detection limits

Figure 2c: Station 3 (S-3)
Depth vs. Total Phosphorus (TP) Concentration

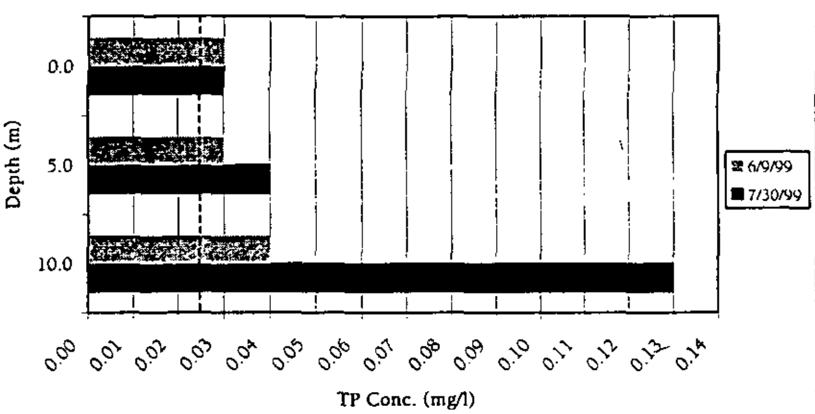


Figure 3a: Easter Brook Station A-1
Total Phosphorus (TP) Concentration

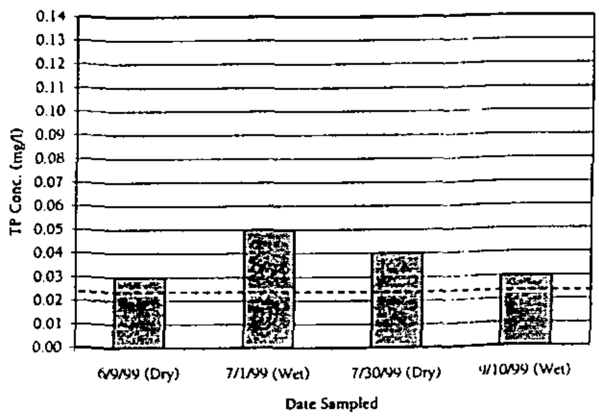


Figure 3b: Easter Brook Station A-2
Total Phosphorus (TP) Concentration

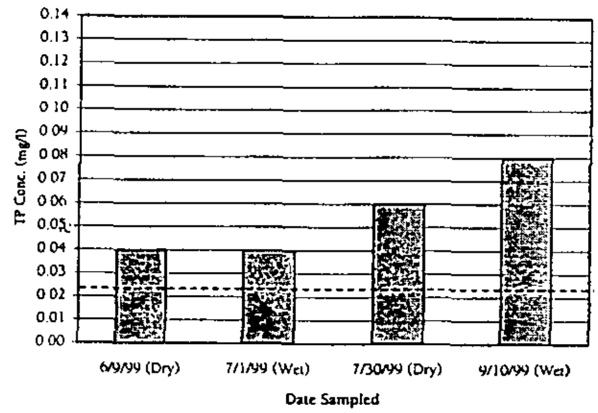


Figure 3c: Easter Brook Station A-3
Total Phosphorus (TP) Concentration

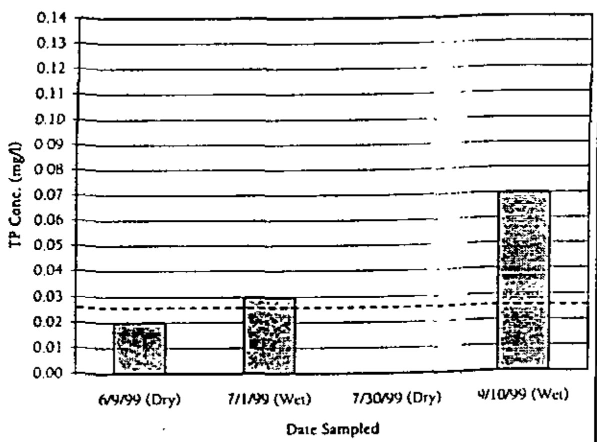


Figure 3d: Easter Brook Station A-4
Total Phosphorus (TP) Concentration

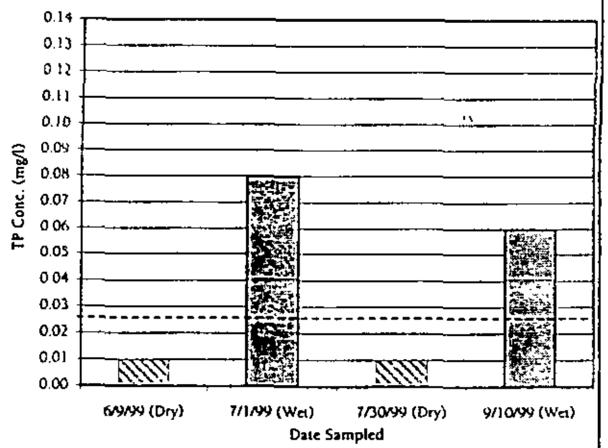
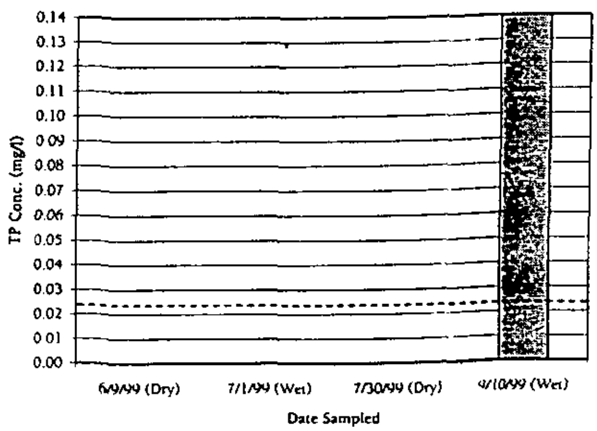


Figure 3e: Easterbrook Station A-5
Total Phosphorus (TP) Concentration



Note: Columns with the striped fill pattern indicate concentration results less than test detection limits

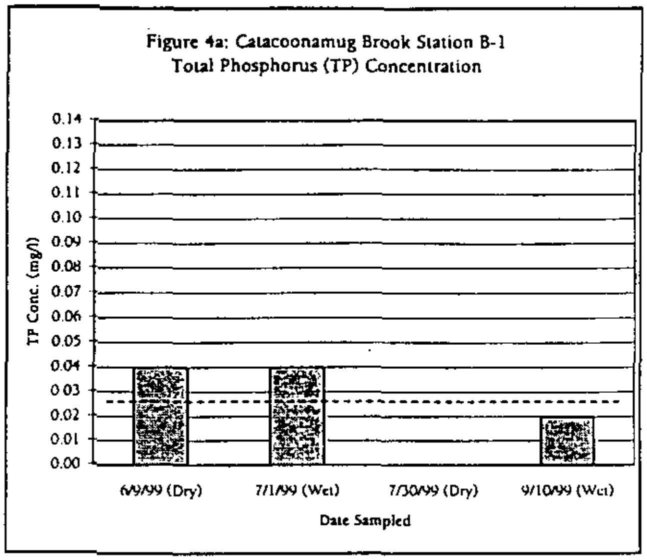


Figure 4a: Catacoonamug Brook Station B-1
Total Phosphorus (TP) Concentration
TP Conc. (mg/l)
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
6/9/99 (Dry)
7/1/99 (Wet)
7/30/99 (Dry)
9/10/99 (Wet)
Date Sampled

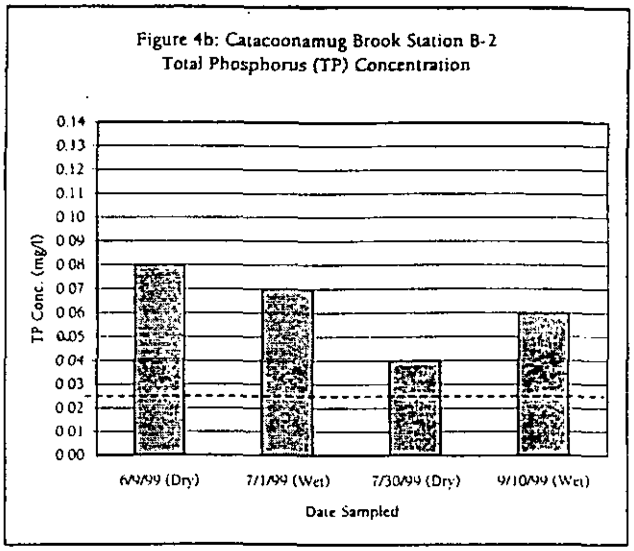


Figure 4b: Catacoonamug Brook Station B-2
Total Phosphorus (TP) Concentration
TP Conc. (mg/l)
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
6/9/99 (Dry)
7/1/99 (Wet)
7/30/99 (Dry)
9/10/99 (Wet)
Date Sampled

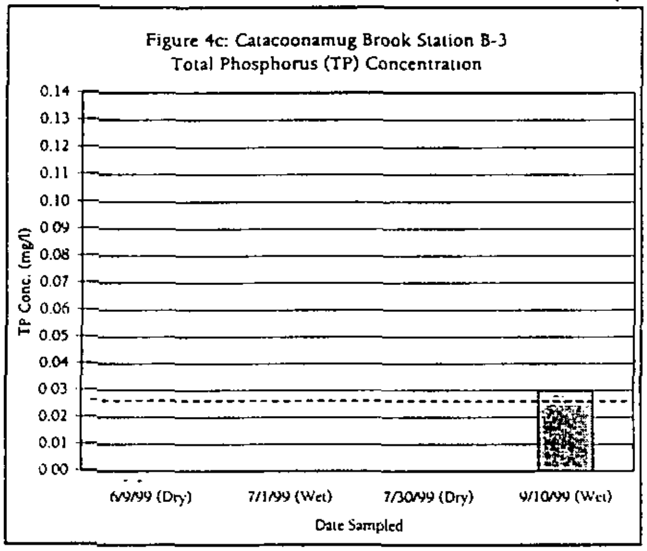


Figure 4c: Catacoonamug Brook Station B-3
Total Phosphorus (TP) Concentration
TP Conc. (mg/l)
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
6/9/99 (Dry)
7/1/99 (Wet)
7/30/99 (Dry)
9/10/99 (Wet)
Date Sampled

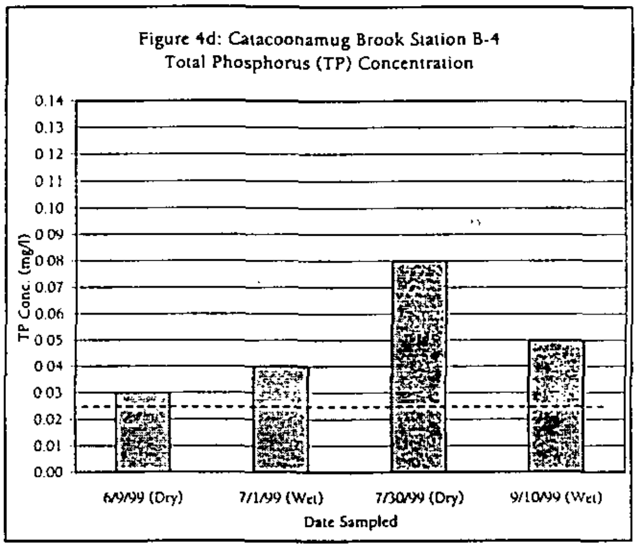


Figure 4d: Catacoonamug Brook Station B-4
Total Phosphorus (TP) Concentration
TP Conc. (mg/l)
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
6/9/99 (Dry)
7/1/99 (Wet)
7/30/99 (Dry)
9/10/99 (Wet)
Date Sampled

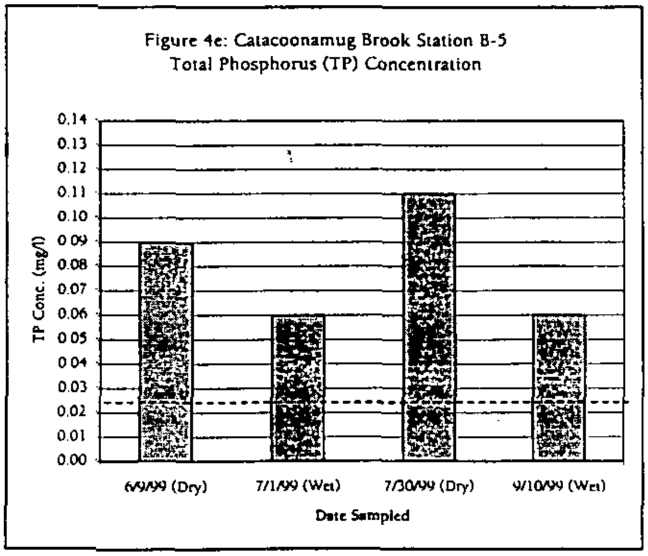


Figure 4e: Catacoonamug Brook Station B-5
Total Phosphorus (TP) Concentration
TP Conc. (mg/l)
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
6/9/99 (Dry)
7/1/99 (Wet)
7/30/99 (Dry)
9/10/99 (Wet)
Date Sampled

Overall, the tributary TP concentrations measured in 1999 were consistently higher than those measured by M&E in 1986. In 1986, the TP concentrations from Catacoonamug Brook (0.025 mg/l) and Easter Brook (0.030 mg/l) inlets were on the threshold of the benchmark for eutrophic conditions. The 1999 data indicates higher TP loading rates that are more likely to consistently support eutrophic conditions. General conclusions on changes in TP loading rates from the smaller tributaries can not be made with confidence due to limited sampling data as a result of near-drought conditions in the summer of 1999.

Table 1-3: Average Dry and Wet Sampling TP Concentrations
** lake inlet sampling stations are highlighted for comparison purposes*

Sampling Station	1999 Avg. Dry TP (mg/l)	1999 Avg. Wet TP (mg/l)	1986 Avg. TP (mg/l)
A-1 (lake inlet)	0.035	0.04	0.025
A-2	0.05	0.06	NA
A-3	0.02	0.05	NA
A-4	< 0.01	0.07	NA
A-5	No flow	0.14	NA
B-1 (lake inlet)	0.04	0.03	0.03
B-2	0.06	0.065	NA
B-3	No flow	0.03	NA
B-4	0.055	0.045	NA
B-5	0.10	0.06	NA
C-1 (lake inlet)	No flow	No flow	0.17
D-1 (lake inlet)	No flow	0.035	0.024
E-1 (lake inlet)	No flow	0.10	0.029
F-1 (lake inlet)	No flow	0.060	0.021

Ammonia-Nitrogen

Nitrogen is the second most important nutrient for algae and plant growth in lakes. Ammonia-nitrogen is readily assimilated by macrophytes, algae, and bacteria. Elevated concentrations in surface waters can be an indicator of pollution from wastewater sources. At high in-lake phosphorus concentrations, nitrogen may become the limiting nutrient to plant growth. Also, nuisance blue-green algal blooms are often associated with lakes that have low nitrogen to phosphorus (N:P) ratios. Since blue-green algae are able to use atmospheric nitrogen gas (N_2) dissolved in lake waters as a nitrogen source, blue-green algae have a competitive advantage over other types of algae and plants which require ammonium and nitrate forms of nitrogen.

In-lake Results: Figures 5a-c illustrate the depth vs. ammonia-nitrogen concentrations. In general, the ammonia-nitrogen concentrations at the in-lake stations did not vary by depth, by station, or by sampling date. Ammonia-nitrogen concentrations at the in-lake stations were beneath the minimum detection limit of 0.2 mg/l (except for the S-3 deep hole, which showed some variation in ammonia-nitrogen concentration by depth and by sampling date).

Tributary Results: Figures 6a-e illustrate the Easter Brook ammonia-nitrogen sampling concentrations. Figures 7a-e illustrate the Catacoonamug Brook ammonia-nitrogen sampling concentrations.

Figure 5a: Station 1 (S-1)
Depth vs. Ammonia Nitrogen Concentration

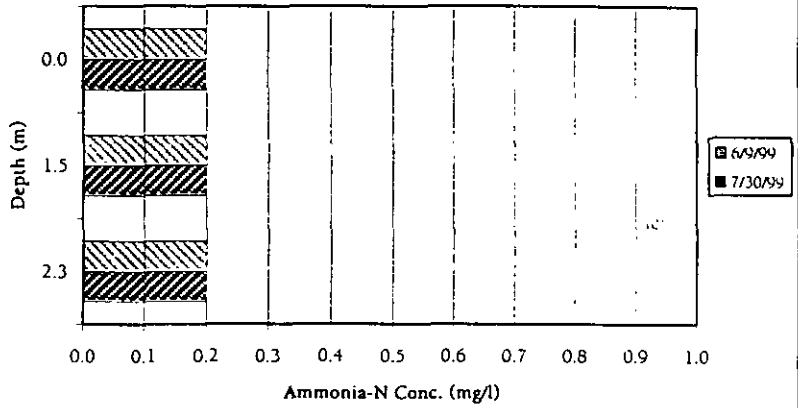
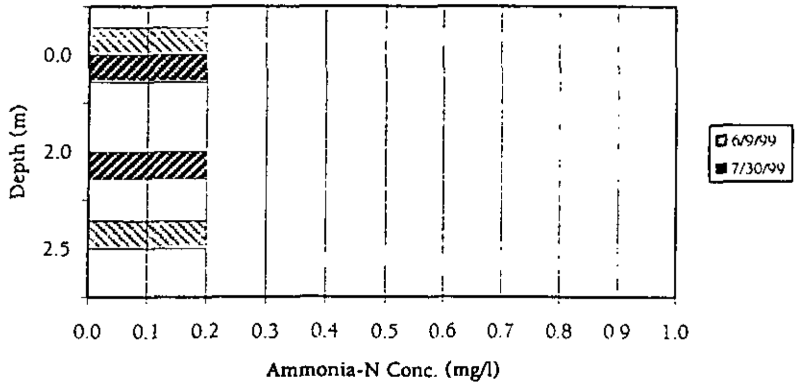


Figure 5b: Station 2 (S-2)
Depth vs. Ammonia Nitrogen Concentration



Note: Columns with the striped fill pattern indicate concentration results less than test detection limits.

Figure 5c: Station 3 (S-3)
Depth vs. Ammonia Nitrogen Concentration

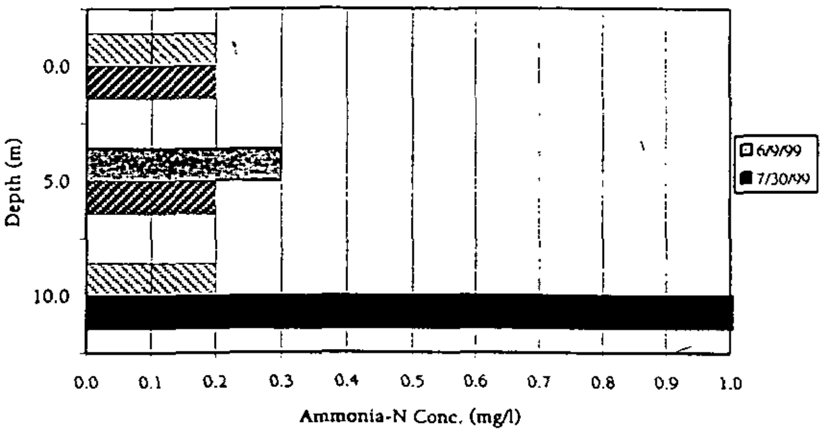


Figure 6a: Easter Brook Station A-1
Ammonia Nitrogen Concentration

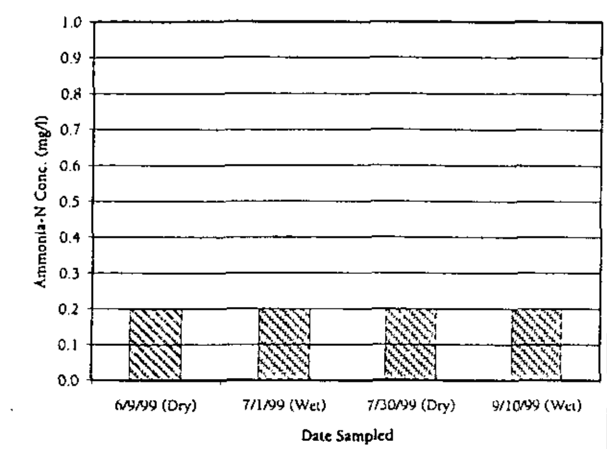


Figure 6b: Easter Brook Station A-2
Ammonia Nitrogen Concentration

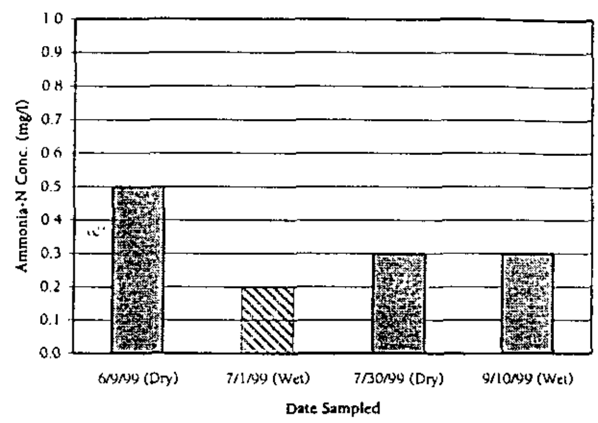


Figure 6c: Easter Brook Station A-3
Ammonia Nitrogen Concentration

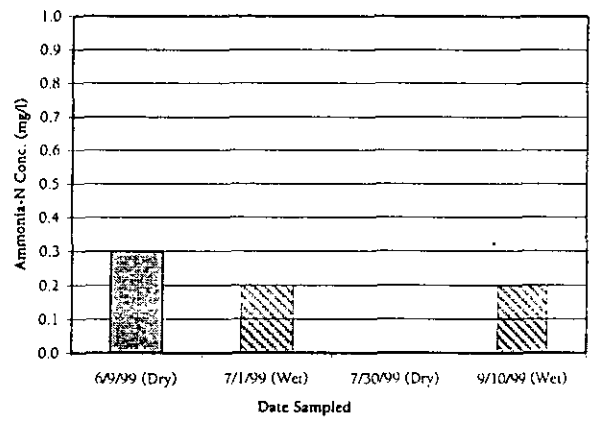


Figure 6d: Easter Brook Station A-4
Ammonia Nitrogen Concentration

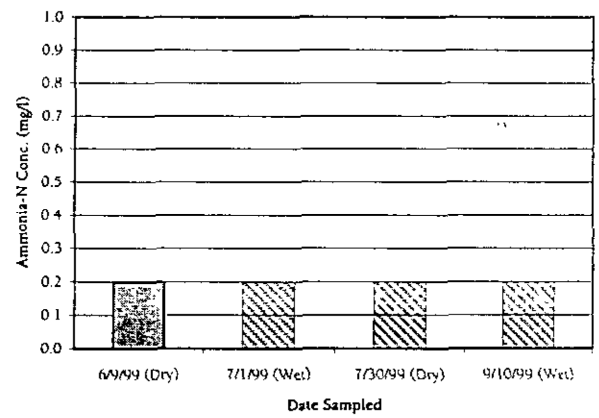
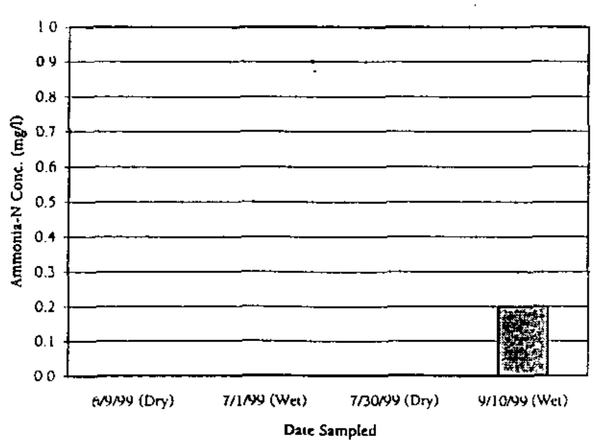


Figure 6e: Easter Brook Station A-5
Ammonia Nitrogen Concentration



Note: Columns with the striped fill pattern indicate concentration results less than test detection limits

Figure 7a: Catacoonamug Brook Station B-1
Ammonia Nitrogen Concentration

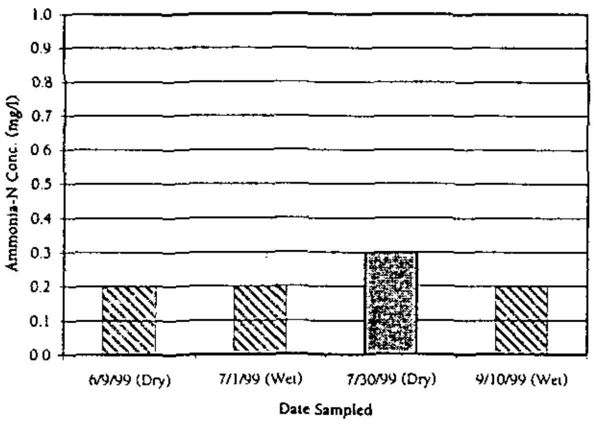


Figure 7b: Catacoonamug Brook Station B-2
Ammonia Nitrogen Concentration

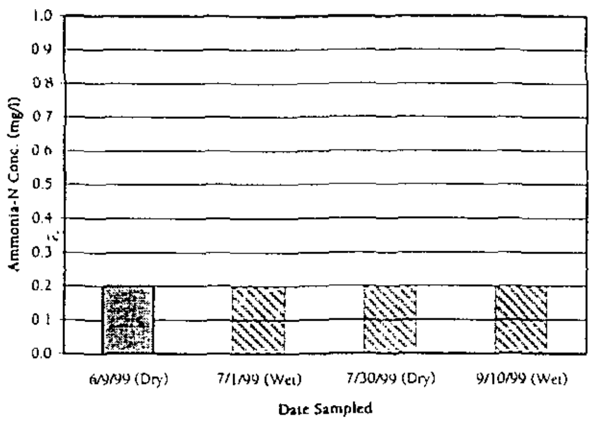


Figure 7c: Catacoonamug Brook Station B-3
Ammonia Nitrogen Concentration

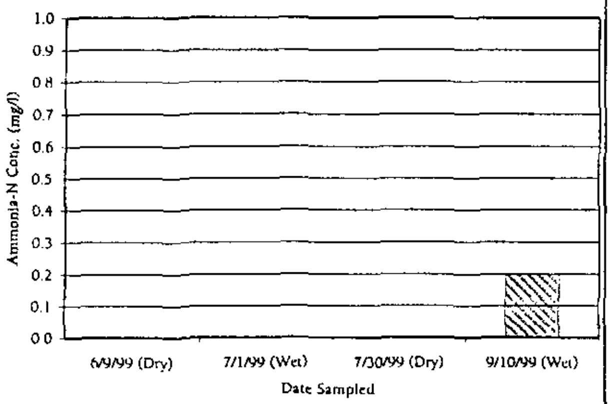


Figure 7d: Catacoonamug Brook Station B-4
Ammonia Nitrogen Concentration

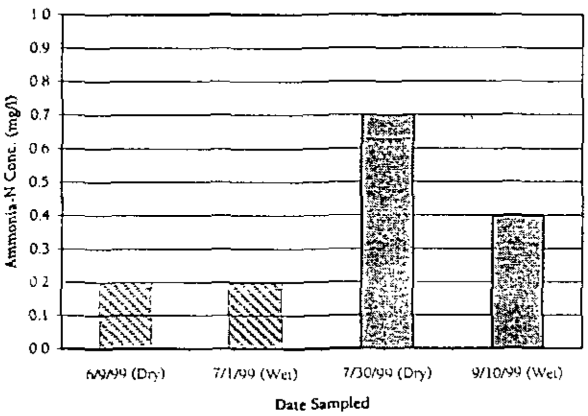
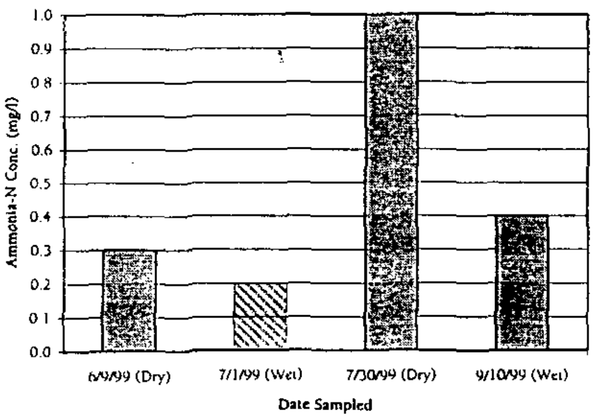


Figure 7e: Catacoonamug Brook Station B-5
Ammonia Nitrogen Concentration



Note: Columns with the striped fill pattern indicate concentration results less than test detection limits

Along both Easter Brook and Catacoonamug Brook, sampling stations upstream of the lake inlet sampling stations (stations A-1 and B-1), exhibited average ammonia-nitrogen concentrations that varied by sampling location and by sampling date (dry vs. wet). The average dry-weather ammonia-nitrogen concentrations at sampling stations A-1 and B-1 were relatively similar with a range of < 0.2 mg/l to < 0.25 mg/l. Stations C-1, D-1, E-1 and F-1 were not sampled on the dry-weather sampling due to lack of flow. The average wet ammonia-nitrogen concentrations at the lake inlet stations were relatively similar with a range of < 0.2 mg/l to < 0.25 mg/l.

Temperature/Dissolved Oxygen (DO) Profile

Deep lakes typically stratify into three distinct thermal layers during the warm summer months. In shallow lakes, such as Lake Shirley, summer stratification may occur weakly or not at all. Temperature profiles are measured at "deep hole" locations in lakes to determine the extent and strength of stratification within the water column. Lake stratification affects the distribution of dissolved oxygen within the water column.

The concentration of oxygen in an aquatic environment is a function of biological processes such as photosynthesis or respiration and physical processes such as water movement or temperature. Therefore, measurements of the distribution of dissolved oxygen (DO) within the water column can provide a great deal of information about the physical and biological processes occurring in a lake.

The Massachusetts Department of Environmental Protection (DEP) surface water quality standard for DO in warm water lakes is 5 mg/l, although concentrations in the hypolimnion (deep waters) are frequently below this level during summer stratification. At the beginning of the summer in temperate lakes, there is typically a high oxygen concentration in the hypolimnion. As the summer progresses, the warmer, well-oxygenated surface waters (epilimnion) become separated from the cooler, denser waters of the hypolimnion. Oxygen in the hypolimnion of nutrient-enriched lakes is consumed and carbon dioxide may increase due to the decomposition of organic matter. Biological and chemical processes that consume oxygen occur constantly in the hypolimnion, and the intensity of these oxygen-consuming processes is directly proportional to the amount of organic matter that reaches the hypolimnion from the upper zones of the lake. As a result, oxygen concentration of the hypolimnion becomes progressively more reduced throughout the summer. The hypolimnion of deep lakes can become anoxic (oxygen depleted) after only a few weeks of summer stratification and remain anoxic until cooler temperatures allow the lake to become uniformly mixed during fall "turnover"(Wetzel 1983). As a result of the anoxic conditions during the summer stratification period, nutrients that are normally bound in the lake sediments can become re-released into the water column, fueling summer plant and algae growth.

Dissolved oxygen concentrations also have an important impact on the fish and other aquatic biota within a lake. Depleted oxygen concentrations have a negative effect on the health and spawning success of fish and other aquatic organisms.

In-lake Results: Figures 8a-b, 9a-b, and 10a-b illustrate the temperature/dissolved oxygen (DO) profiles for Site 1 (north basin), Site 2 (middle basin), and Site 3 (south basin deep hole), respectively.

Figure 8a: Station 1 (S-1)
Depth vs. Temperature and Dissolved Oxygen (6/9/99)

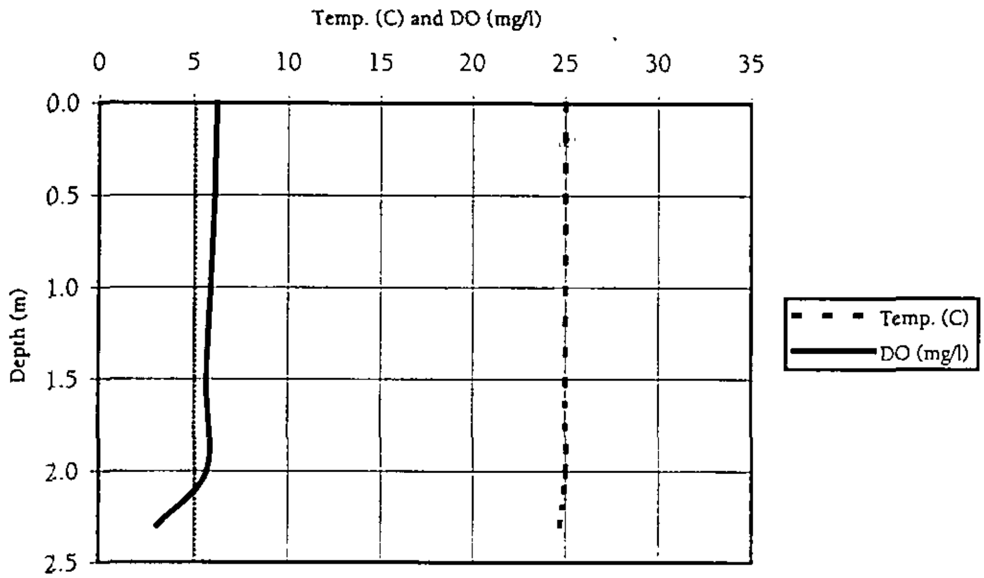


Figure 8b: Station 1 (S-1)
Depth vs. Temperature and Dissolved Oxygen (7/30/99)

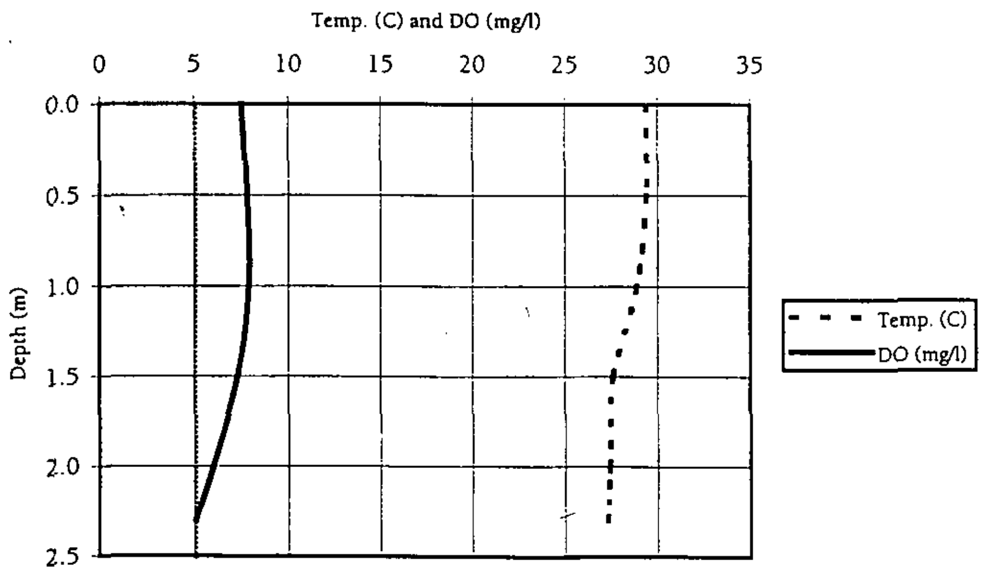


Figure 9a: Station 2 (S-2)
Depth vs. Temperature and Dissolved Oxygen (6/9/99)

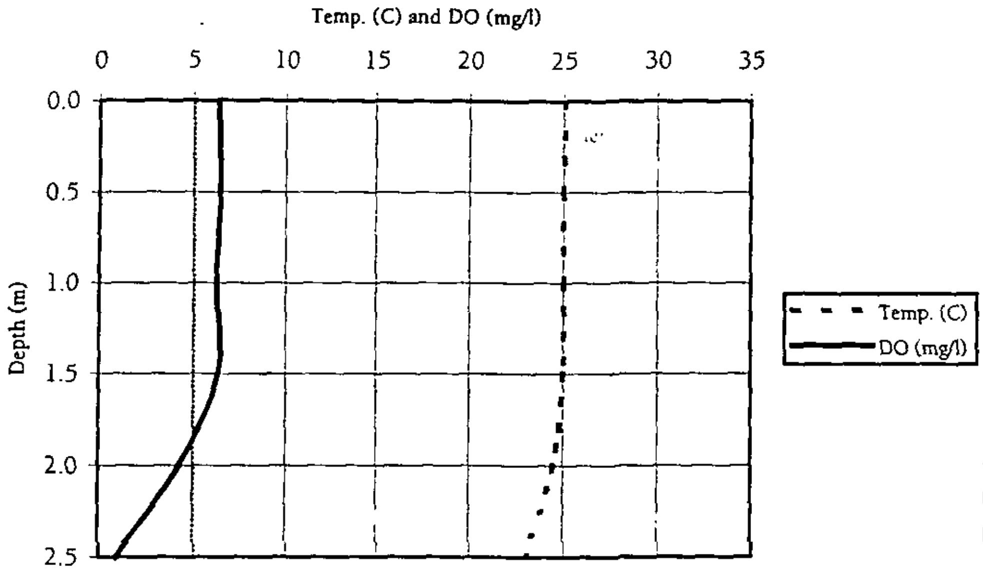


Figure 9b: Station 2 (S-2)
Depth vs. Temperature and Dissolved Oxygen (7/30/99)

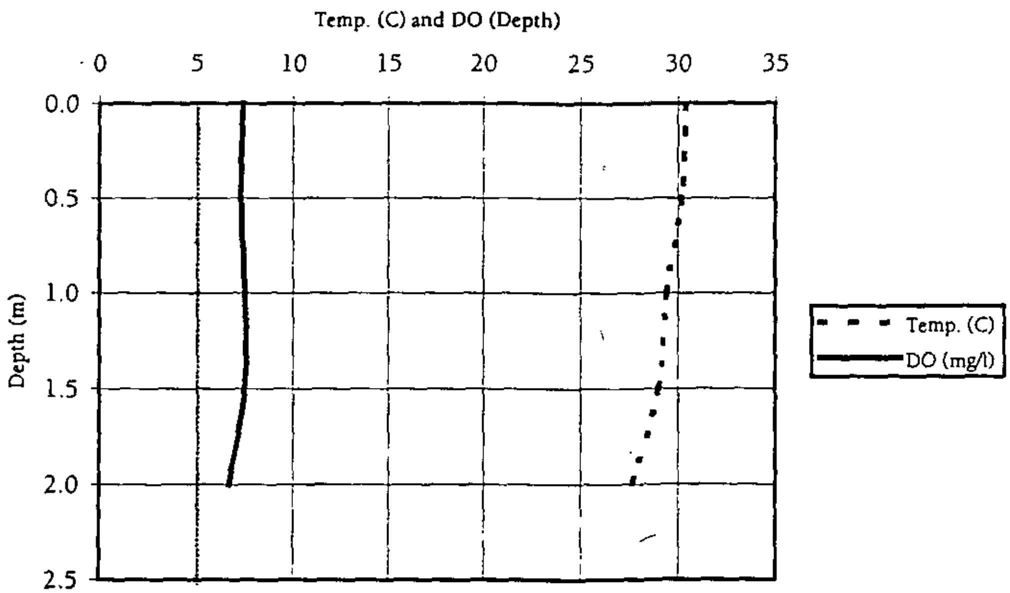


Figure 10a: Station 3 (S-3)
Depth vs. Temperature and Dissolved Oxygen (6/9/99)

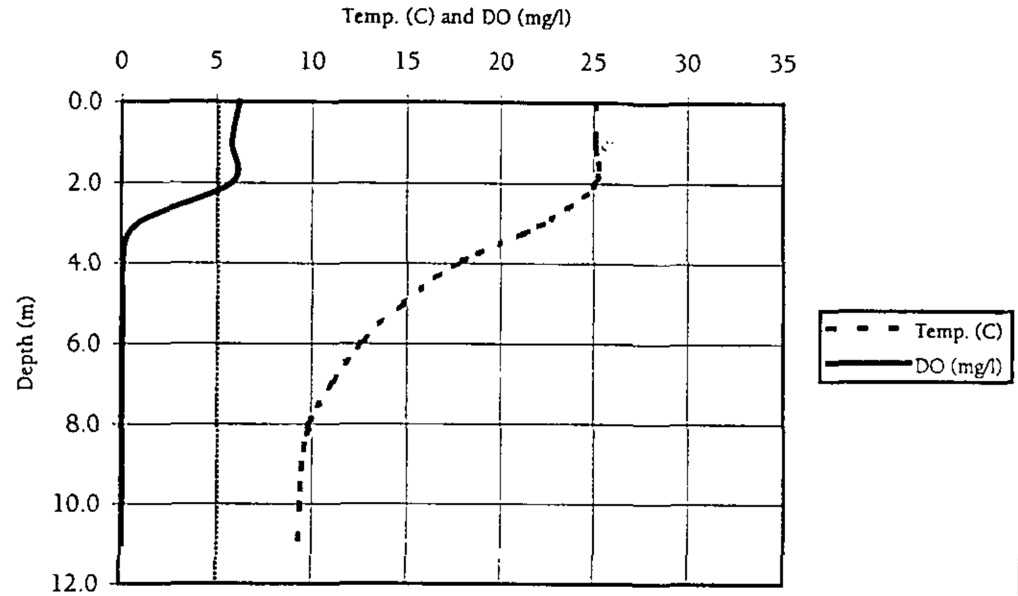
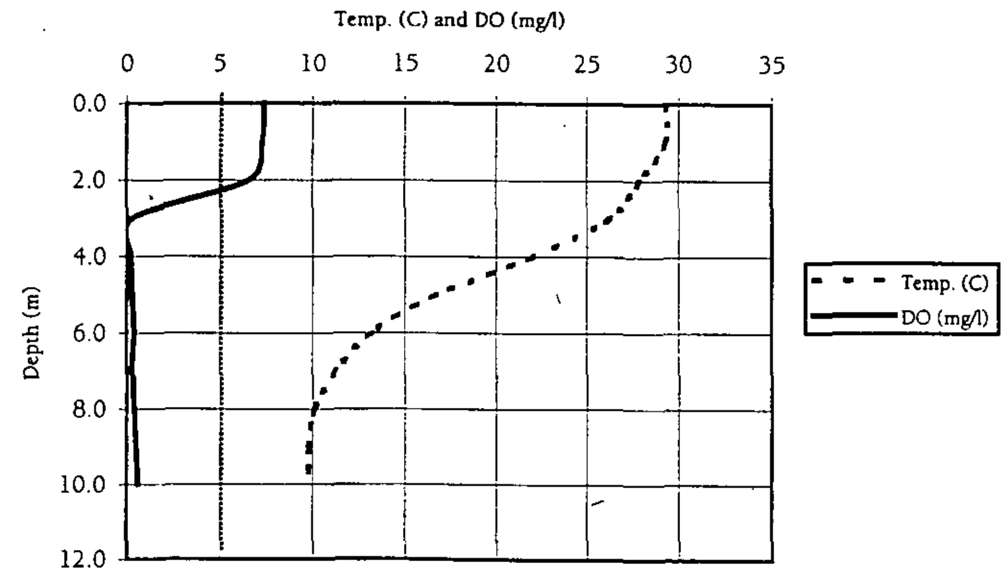


Figure 10b: Station 3 (S-3)
Depth vs. Temperature and Dissolved Oxygen (7/30/99)



DO profiles for Site 1 (north basin) and Site 2 (middle basin) indicate essentially uniform conditions from the surface to the lake bottom. Like most of Lake Shirley, these fairly shallow "deep hole" stations are well mixed and do not experience significant thermal stratification during the summer. On both sampling dates, DO concentrations were adequate for fish populations throughout the water column at both stations, and were above the water quality standard of 5 mg/l.

The temperature/DO profile for Site 3 (south basin deep hole) exhibited significant thermal stratification on both sampling dates. Specifically, on both dates, a thermocline was present between roughly 2.0 meters (6.6 feet) and 6.0 meters (19.7 feet). The thermocline is a zone where temperature and water density drop rapidly with increasing depth, preventing mixing between the surface and bottom waters. DO concentrations dropped below the water quality standard of 5.0 mg/l at depths greater than 2.0 meters and became almost completely anoxic (<1.0 mg/l) below 3.0 meters (9.8 feet).

When the 1999 BSC data is compared to the data collected by M&E on July 8, 1986, it appears that the vertical extent and severity of summer oxygen depletion has increased significantly at Site 3. Although the July 1986 temperature profile was almost identical to July 1999 temperature profile, the 1986 DO concentrations were significantly higher and declined more gradually with increasing depth compared to July 1999. In 1986, the DO did not drop below 5.0 mg/l until roughly 5 meters (16.4 feet) and did not drop below 1.0 mg/l until 9.0 meters (29.5 feet).

The increased area and severity of oxygen depletion that was observed during the 1999 sampling period is an indicator that the lake has become more eutrophic since 1986. These conditions indicate that seasonal nutrient recycling from the deep hole sediments has probably increased since 1986. However, considering the small size of the deep hole area (11 acres) when compared to the total size of Lake Shirley (354 acres), the overall contribution of sediments to Lake Shirley's nutrient budget is still likely to be insignificant.

<u>Clarity (Secchi disk)</u>

The Secchi disk is a weighted black and white disk which is lowered into the water by a calibrated chain until it is no longer visible. The Secchi disk provides a measure of water clarity (light penetration) within the water column, which is primarily a function of algal productivity and turbidity caused by suspended particulate matter. Water clarity impacts the growth of rooted aquatic plants by determining the depths to which sunlight can penetrate to the lake sediments.

In-lake Results: As shown in Figure 11, the Secchi disk readings at the three in-lake stations ranged from 5.0 to 5.8 feet on the first sampling date (June 9^{th}). On the second sampling date (July 30^{th}) all stations had readings of 3.8 feet. Both sampling dates were during the mid-week, at times of relatively low motor boat activity on the lake. In general, Secchi disk readings of less than 6 feet indicate eutrophic conditions. The state safety standard for swimming beaches is a minimum Secchi disk clarity of 4 feet, which was not met during the July sampling at any of the stations.

Compared to data from 1986, the water clarity at Lake Shirley has declined significantly. The 1986 Secchi disk ranged from 7 to 10 feet at Site 1, and ranged from 9 to 14 feet at Site 3, with no obvious seasonal pattern (M&E). The decrease in water clarity since 1986 appears to be function of increased algal productivity, and indicates that the lake has become more eutrophic.

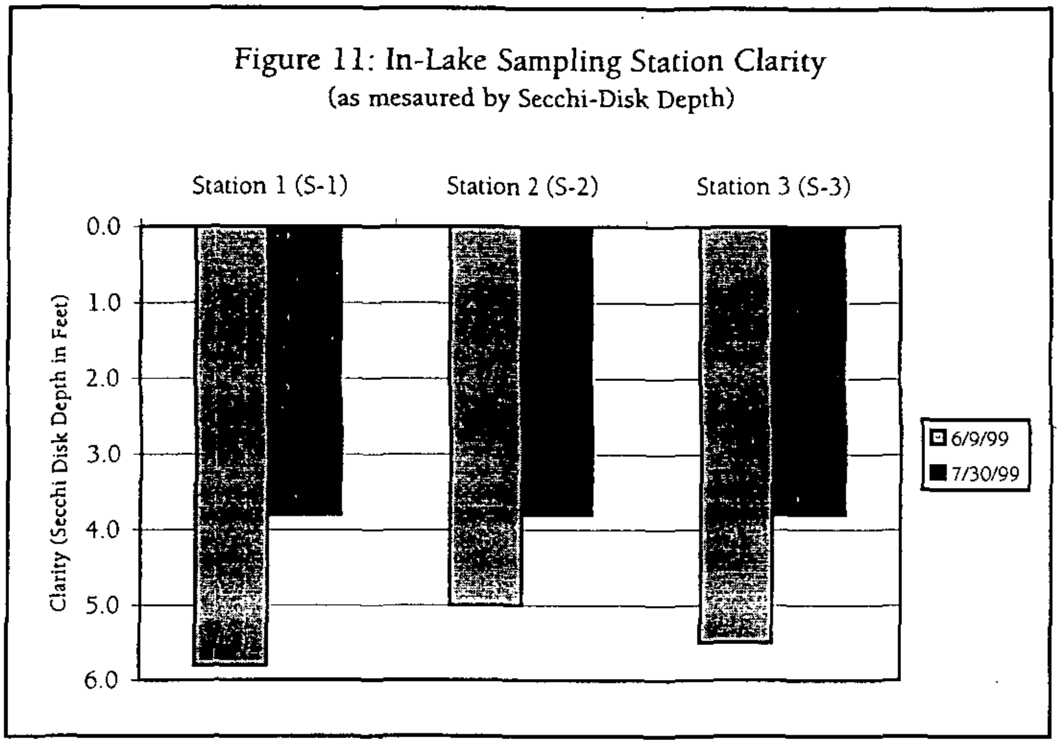


Figure 11: In-Lake Sampling Station Clarity
(as mesaured by Secchi-Disk Depth)
Station 1 (S-1)
Station 2 (S-2)
Station 3 (S-3)
Clarity (Secchi Disk Depth in Feet)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
6/9/99
7/30/99

pH

pH is a measure of acidity based on the presence of hydrogen ions. A pH of 7.0 is neutral, while values below 7.0 indicate acidic waters and values above 7.0 indicate basic waters. The pH level of a lake affects nutrient and sediment interactions and the composition and distribution of the fish population. The water quality standard for Massachusetts lakes is between a pH of 6.5 and 8.0. Most fish can not tolerate a pH below 4 and above 11, and their growth and health is affected by long-term exposure to waters with pH less than 6.0 and greater than 9.5 (Boyd, 1982).

In-lake Results: The pH readings throughout the water column at stations S-1 and S-2 were generally within the normal range for Massachusetts lakes, although the surface water pH was slightly basic (pH 8.2) on the second sampling date (July 30th). The readings at these two fairly shallow locations are expected to be representative of most of the lake. However, station S-3 (the deep hole), exhibited a dramatic fluctuation in pH levels from the surface (pH 8.5) to the lake bottom (pH 4.3). On both sampling dates, at station S-3 the pH dropped below 6.0 at depths greater than 4.0 meters (13.1 feet). The reduced pH found at depth in the deep hole can be attributed to biological decomposition processes that lead to anoxic (oxygen depleted) conditions and other chemical reactions which reduce pH.

As described above, the level of oxygen depletion in the deep hole hypolimnion has increased dramatically since 1986. The corresponding decline in hypolimnetic pH levels is equally dramatic, with July 1986 data showing pH at station S-3 ranging only from 6.4 to 6.8. This data further indicates increasingly eutrophic conditions and a degradation of fish habitat at the south basin deep hole.

Tributary Results: The pH measurements from the Catacoonamug Brook inlet (station B-1; pH 6.7) and Easter Brook inlet (station A-1; pH 7.2 –7.4) were consistent on both sampling dates and well within the normal range for Massachusetts lakes.

Specific Conductance

Specific conductance measures the ability of the water to conduct electricity by measuring the presence of ions in solution. Chloride is typically the predominant ion found in surface waters. The primary cultural (man-made) sources of chloride ions in surface waters include wastewater discharges and road salt runoff. The primary natural sources of chloride ions in surface waters include the weathering of soils and rocks, and wet and dry precipitation. Regional variations in watershed geology result in wide fluctuations in specific conductance levels. However, it is important to sample for specific conductance in surface waters since abnormally high values can be an indicator of pollutant sources of ions, such as road salting, wastewater discharges, and runoff from urbanized areas.

In-lake Results: Specific conductance measurements at the in-lake sampling stations ranged from 0.205 mS/cm to 0.268 at mS/cm, with the highest readings at the bottom of the station S-3 deep hole attributed to chemical reactions occurring at the sediment-water interface. These measurements are well within the normal range for lakes in Massachusetts.

Tributary Results: Specific conductance measurements taken at the Easter Brook inlet (station A-1) ranged from 0.252 mS/cm to 0.299mS/cm. The Catacoonamug Brook inlet (station B-1) ranged from 0.160 mS/cm to 0.195mS/cm. Based on the amount of surface water contributed to Lake Shirley from each of these streams, these measurements are consistent with the in-lake concentrations and are well within the normal range for lakes in Massachusetts.

1.3 GIS Land Use Analysis

In order to develop a predictive model for nutrient loading from the Lake Shirley watershed, the land uses of each sub-watershed area were analyzed. The Lake Shirley watershed and sub-watersheds were delineated using United States Geological Survey (USGS) Topographic Maps, the Arcview PC GIS System (ESRI, 1995), and information provided from the Massachusetts Geographic Information System (MassGIS). The land uses for the entire watershed and for each of the 6 sub-watersheds were estimated based on the MassGIS digital land use maps (Figure 12).

Watershed Area: According to the MassGIS land use information, Lake Shirley and its watershed covers an area of approximately 9050 acres. Six sub-basins were identified within the watershed which ranged in size from approximately 180 acres to 5474 acres, as summarized in Table 1-4.

Watershed Land Use: Table 1-4 provides a land use summary of the entire watershed, including a breakdown of land uses for each sub-watershed, and also including the area of coverage of each land use and the percent coverage of each land use type. Nineteen (19) land use categories within the Lake Shirley watershed are identified by MassGIS. Overall, the most prevalent land use type in the Lake Shirley watershed is "*Forest*" (52% of the entire watershed), followed by "*Cropland*" (12%) and "*Residential: Lots >1/2 acre*" (8%).

Figure 12: Lake Shirley Watershed Land Uses

Table 1-4: Lake Shirley Watershed Land Use Area Coverages (acres)

LANDUSE	TOTAL AREA	AREA A	AREA B	AREA C	AREA D	AREA E	AREA F
Cropland (acres)	1046.75	324.57	715.81	6.37	0.00	0.00	0.00
(%)	11.57%	16.81%	13.08%	3.51%	0.00%	0.00%	0.00%
Pasture (acres)	235.57	79.36	139.90	0.00	0.00	13.05	3.26
(%)	2.60%	4.11%	2.56%	0.00%	0.00%	3.55%	0.36%
Forest (acres)	4691.60	1085.22	2847.34	132.13	155.14	135.06	336.70
(%)	51.84%	56.21%	52.01%	72.75%	86.37%	36.75%	36.73%
Freshwater Wetland (acres)	346.08	31.62	280.39	0.00	1.31	24.88	7.88
%	3.82%	1.64%	5.12%	0.00%	0.73%	6.77%	0.86%
Mining (acres)	217.53	64.43	13.10	0.00	0.00	130.18	9.81
(%)	2.40%	3.34%	0.24%	0.00%	0.00%	35.43%	1.07%
Open Land (acres)	204.44	57.78	107.77	0.09	0.00	38.37	0.43
(%)	2.26%	2.99%	1.97%	0.05%	0.00%	10.44%	0.05%
Open Land: Powerlines (acres)	21.72	4.82	0.00	0.00	0.00	16.90	0.00
(%)	0.24%	0.25%	0.00%	0.00%	0.00%	4.60%	0.00%
Recreation (acres)	40.54	10.01	30.53	0.00	0.00	0.00	0.00
(%)	0.45%	0.52%	0.56%	0.00%	0.00%	0.00%	0.00%
Water Based Recreation (acres)	4.84	0.00	2.62	0.00	0.00	0.00	2.22
(%)	0.05%	0.00%	0.05%	0.00%	0.00%	0.00%	0.24%
Residential: lots = or < 1/2 acre (acres)	635.10	22.46	524.67	4.19	0.00	0.00	83.78
(%)	7.02%	1.16%	9.58%	2.31%	0.00%	0.00%	9.14%
Residential: lots > 1/2 acre (acres)	738.71	91.58	483.52	37.47	23.17	1.49	101.48
(%)	8.16%	4.74%	8.83%	20.63%	12.90%	0.41%	11.07%
Commercial (acres)	51.86	21.91	29.95	0.00	0.00	0.00	0.00
(%)	0.57%	1.13%	0.55%	0.00%	0.00%	0.00%	0.00%
Industrial (acres)	38.62	38.62	0.00	0.00	0.00	0.00	0.00
(%)	0.43%	2.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Urban Open (parks, cemeteries) (acres)	121.20	28.44	92.44	0.00	0.00	0.00	0.33
(%)	1.34%	1.47%	1.69%	0.00%	0.00%	0.00%	0.04%
Transportation (acres)	39.10	26.81	12.29	0.00	0.00	0.00	0.00
(%)	0.43%	1.39%	0.22%	0.00%	0.00%	0.00%	0.00%
Transportation Facilities (acres)	1.27	1.27	0.00	0.00	0.00	0.00	0.00
(%)	0.01%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
Waste Disposal (acres)	18.59	11.07	1.01	0.00	0.00	6.51	0.00
(%)	0.21%	0.57%	0.02%	0.00%	0.00%	1.77%	0.00%
Water (acres)	493.95	3.44	118.73	0.00	0.00	1.05	370.74
(%)	5.46%	0.18%	2.17%	0.00%	0.00%	0.28%	40.45%
Woody Perennial (acres)	102.87	27.41	74.10	1.37	0.00	0.00	0.00
(%)	1.14%	1.42%	1.35%	0.75%	0.00%	0.00%	0.00%
Total (acres)	9050.33	1930.82	5474.16	181.62	179.62	367.47	916.63
Total of Entire Watershed (%)	100.00%	21.33%	60.49%	2.01%	1.98%	4.06%	10.13%

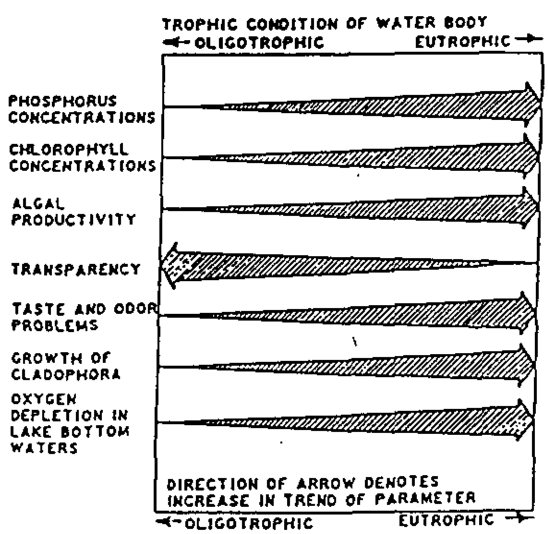
1.4 Land Use Nutrient Export Model

Lake eutrophication is both a natural and culturally induced phenomenon (Reckhow et al., 1980). Natural eutrophication is associated with lake aging, the natural process in which a lake fills in over time with nutrients and erosional materials carried in by the tributary streams, with materials deposited directly through the air, and with materials produced in the lake itself (NHDES, 1989). Cultural eutrophication is associated with the sediment and nutrient loading into a lake that is accelerated by human activity, such as the clearing of forests for land development, the discharge of sewage effluent, and nutrient enriched runoff from roads, farms and fertilized lawns.

Land uses within a watershed determine the amount and type of nutrient loading into a lake. In general, runoff from developed lands typically contains a higher nutrient content than runoff from undeveloped, densely vegetated, or forested lands. Surface water runoff from fertilized agricultural lands often contains large quantities of dissolved nutrients and nutrients attached to sediment particles, including phosphorus and nitrogen. In addition, runoff from the impervious surfaces of residential, industrial, and commercially developed lands, runoff from fertilized lawns and gardens, lechate from faulty septic systems, and effluent from wastewater treatment plants typically contains elevated concentrations of phosphorus, nitrogen and other pollutants.

As nutrient loading to a waterbody increases, a number of water quality problems may occur. As illustrated in Figure 13, water quality problems associated with increased nutrient loading include the following: increased growth of algae and/or aquatic vegetation; decreased water clarity; depletion of dissolved oxygen concentrations in the lake bottom waters; and taste and/or odor problems. As a result, high levels of nutrient loading may impair the use of a waterbody for aesthetic, recreational, and drinking water purposes.

Figure 13: Symptoms of Eutrophication
(Source: Figure 12.12 in Novotny, 1994)



While natural eutrophication is a relatively slow and "largely irreversible process", cultural eutrophication is "an often rapid, possibly reversible process" (Reckhow et al., 1980). It is important that lake managers conduct nutrient loading studies in order to identify areas where management practices may be employed within a watershed in an effort to reduce nutrient loading and to ultimately slow the process of cultural eutrophication.

The purpose of the nutrient loading modeling component of the Lake Shirley Nutrient Loading Study is to quantify the annual external total phosphorus (TP) loading to the lake on a sub-watershed basis so that the relationship of TP loading within the watershed can be examined.

Total Phosphorus Loading Modeling Methodology

The first step in a nutrient loading study is to quantify the current nutrient load for the lake. For this study, nutrient loading estimates were derived by using a land-use export model,,calibrated with water quality data from the 1999 sampling program. As pointed out by Knisel (1985), "the burden of proof is upon the user to decide which model is appropriate for the problem on hand. The user must learn the model concepts, assumptions, limitations and whether or not it will adequately treat the problem of concern."

After a review of the available nutrient loading models, BSC selected the nutrient loading model that Isaac and Mattson (1999) of the Massachusetts Department of Environmental Protection (DEP) recently developed in an effort to establish Total Maximum Daily Loads (TMDLs) of total phosphorus for Massachusetts lakes. This model is fully described in the Lake and Reservoir Management Journal (Volume 15, No. 3, September 1999) in a paper titled "Calibration of Phosphorus Export Coefficients for Total Maximum Daily Loads of Massachusetts Lakes".

In developing the model, the DEP re-analyzed the land use export coefficients of previously published nutrient loading diagnostic/feasibility studies. The DEP found that the literature values for phosphorus loading per unit area of land tended to overestimate the phosphorus loading to Massachusetts lakes. The DEP used a stagewise regression technique to screen a variety of models and to select export coefficients that were reasonable for Massachusetts lakes, based on the literature, and which offered a good fit to the data. The final DEP model was verified by predicting phosphorus loading to an independent set of Massachusetts lakes with an average error of 36%.

The Phosphorus Loading model that the DEP developed is:

$$L_{ex} = (0.5 * \text{\# house septics}) + (0.13 * \text{forest ha}) + (0.3 * \text{rural ha}) + (14 * (\text{urban ha})^{0.5})$$

where:

L_{ex} is the external total phosphorus loading in $kg*yr^{-1}$
0.5 is the septic export loading coefficient with units of $kg*ha^{-1}*yr^{-1}$
0.13 is the forest loading coefficient with units of $kg*ha^{-1}*yr^{-1}$
0.3 is the rural loading coefficient with units of $kg*ha^{-1}*yr^{-1}$
0.14 is the urban loading coefficient with units of $kg*ha^{-1}*yr^{-1}$
(Note: ha = hectares)

According to the model equation, per unit area, runoff from urban land contains the greatest amount of TP, while runoff from forest land contains the lowest amount of TP.

The model combines land use types identified by MassGIS into three major categories of similar nutrient export as follows: 1) Forest, 2) Rural, and 3) Urban. The DEP concedes that "while classification is simple and convenient, errors may be introduced" (Mattson and Isaac, 1999). The corresponding MassGIS land use types (and code numbers) in each category are presented below in Table 1-5.

Table 1-5: DEP Simplified Land Use Classifications

DEP Model Land Use Categories	MassGIS Land Use Types (MassGIS code #)
Forest	(3) Forest
Rural	(13) Low-density residential, lots > ½ acre (1) Cropland (2) Pasture (6) Open Land (7-9) Recreation (17) Urban open land (21) Woody perennial
Urban	(10-12) Residential, lots < ½ acre (15) Commercial (16) Industrial (18) Transportation (19) Waste Disposal (5) Mining

Atmospheric deposition of phosphorus directly to lakes in Massachusetts is generally relatively small and was not significant in the model regression, possibly because lakes act as a sink rather than a source of nutrients (Mattson and Isaac, 1999). Wetlands and open water were not used in the phosphorus loading model for similar reasons.

A separate variable is used to account for septic system phosphorus inputs. Septic inputs were estimated based on assumptions typically used in nutrient loading studies, which closely follow the recommendations of Reckhow et al. (1980). The model estimates that homes in non-urban areas within 100 meters of the lake were the only source of septic system phosphorus inputs.

<u>Application of the Phosphorus Loading Model to Lake Shirley</u>

Land use estimates: To model the external TP load to Lake Shirley, MassGIS land use categories were combined into the three land use categories discussed above and shown in Table 1-6.

Table 1-6: Lake Shirley Watershed Simplified Land Use Area Coverages (in hectares)
(Note: 1 acre = 0.405 hectares)

LANDUSE	TOTAL AREA	AREA A	AREA B	AREA C	AREA D	AREA E	AREA F
Forest (ha)	1900.20	439.54	1153.24	53.52	62.84	54.70	136.37
(%)	51.84%	56.21%	52.01%	72.75%	86.37%	36.75%	36.73%
Rural (ha)	1019.29	252.72	666.94	18.35	9.39	28.27	43.63
(%)	27.81%	32.32%	30.08%	24.94%	12.90%	19.00%	11.75%
Urban (ha)	405.86	75.57	235.33	1.70	0.00	55.36	37.91
(%)	11.07%	9.66%	10.61%	2.31%	0.00%	37.20%	10.21%
Total (hectares)	3325.35	767.82	2055.50	73.56	72.22	138.34	217.91
Total (%)	90.72%	98.18%	92.71%	100.00%	99.27%	92.95%	58.69%

(Note: The MassGIS land use categories of "*Freshwater Wetland*" and "*Open Water*" were not included in the model since these land uses typically act as nutrient sinks, rather than sources, as discussed previously. Therefore, the simplified land use area estimated percentages for certain sub-watersheds do not add up to 100%. In addition, note that the area coverage estimates were converted from units of acres to units of hectares, as required by the model.)

Septic system input estimates: The model estimates that homes in non-urban areas within 100 meters of the lake were the sources of septic system phosphorus. Maps of the property lots around Lake Shirley were obtained from the Lunenburg Assessor's Office and used to count the number of developed properties located within 100 meters of the lakeshore. The most recent USGS Quadrangle Map (Ayer Quadrangle, 1988) was used to estimate the number of developed properties in Shirley within 100 meters of the lake.

224 developed properties were identified within 100 meters of Lake Shirley. Based on lot size and location, 219 of these lots (98%) were determined to have septic systems within 100 meters of the lake. Although actual septic system locations were not determined, only 5 lots adjacent to the lake were large enough to potentially site a septic system more than 100 meters from the shore. The 1986 property owner survey conducted by M&E is consistent with this analysis. According to the survey, 91% of respondents had septic systems within 250 feet (76.2 meters) of the lake.

Model Calibration: While the DEP model is a simple and powerful predictive tool, it generalizes watershed conditions for Massachusetts lakes. To tailor the model to conditions at Lake Shirley and its watershed, water quality data collected by BSC in 1999 was used to "calibrate" the model. Although field data was used to more accurately predict tributary nutrient loading concentrations, the land use relationships predicted in the original DEP model were kept intact.

<u>Modeling Results/Analysis</u>

The results of the total phosphorus (TP) loading model are summarized below in Table 1-7. A spreadsheet of the model calculations and calibration with field data is presented in Appendix 2.

Table 1-7: Phosphorus Loading Model Results

Sub-watershed	Calibrated Annual External TP Load (kg/year)	% of Total Annual External TP Load
A	125.9	19.3 %
B	279.1	42.8 %
C	15.2	2.3 %
D	5.4	0.8 %
E	59.2	9.1 %
F (surface water loading)	57.8	8.9 %
F (septic system loading)	109.5	16.8 %
Total loading	652.1	100.0 %

It is important to note that the total phosphorus loading estimate (652.1 kg/year) focuses on surface water sources from tributaries or direct watershed runoff. Because septic system inputs are such a significant percentage of the loading from sub-watershed F, these inputs are also estimated. For purposes of comparison with the annual phosphorus budget from the 1986 M&E study (664 kg/yr.), it should be noted that M&E also estimated loading from non- surface water sources that were not within the scope of this study, such as direct precipitation, sediments and groundwater. When these additional sources are subtracted from the 1986 estimate, the estimated annual phosphorus loading from surface water and septic inputs becomes 519 kg/year.

Figure 14 presents the estimated external TP load in kg/yr. by sub-watershed while Figure 15 presents the relative phosphorus load for each sub-watershed on a per acre basis. Figure 15 allows for a comparison of phosphorus inputs from each sub-watershed, while accounting for different loading rates due to land uses and attenuation mechanisms. Furthermore, Figure 16 illustrates the TP load for each sub-watershed by land use.

Figure 14: Estimated External Total Phosphorus Load for Each Sub-Watershed
Total Load to Lake Shirley (excluding septics) = 542 kg/year (approx.)

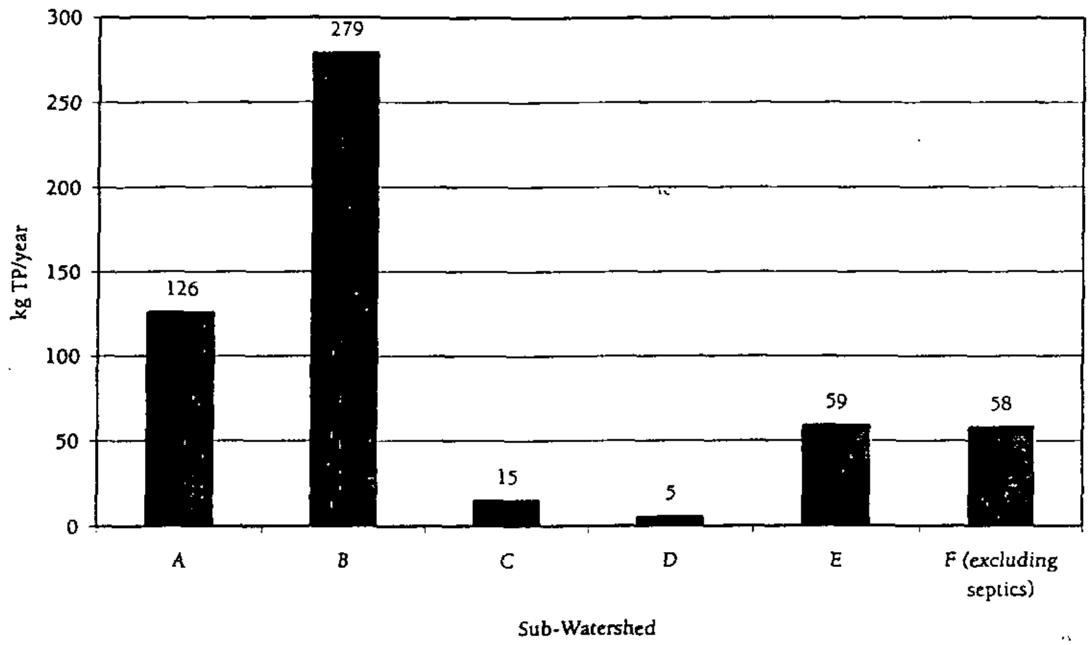
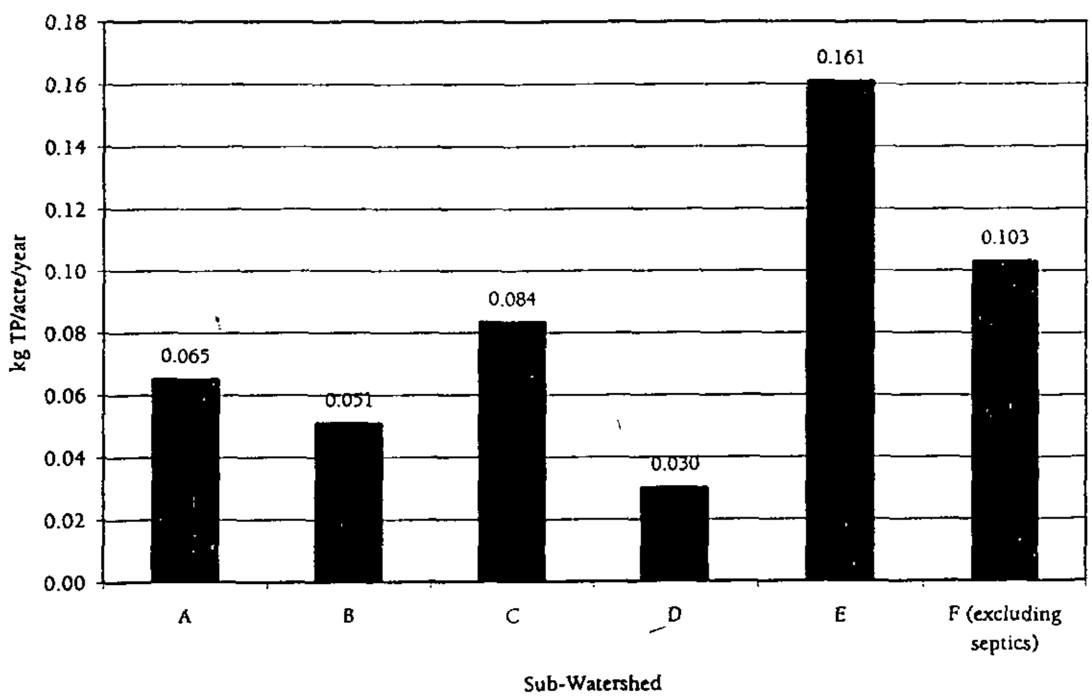


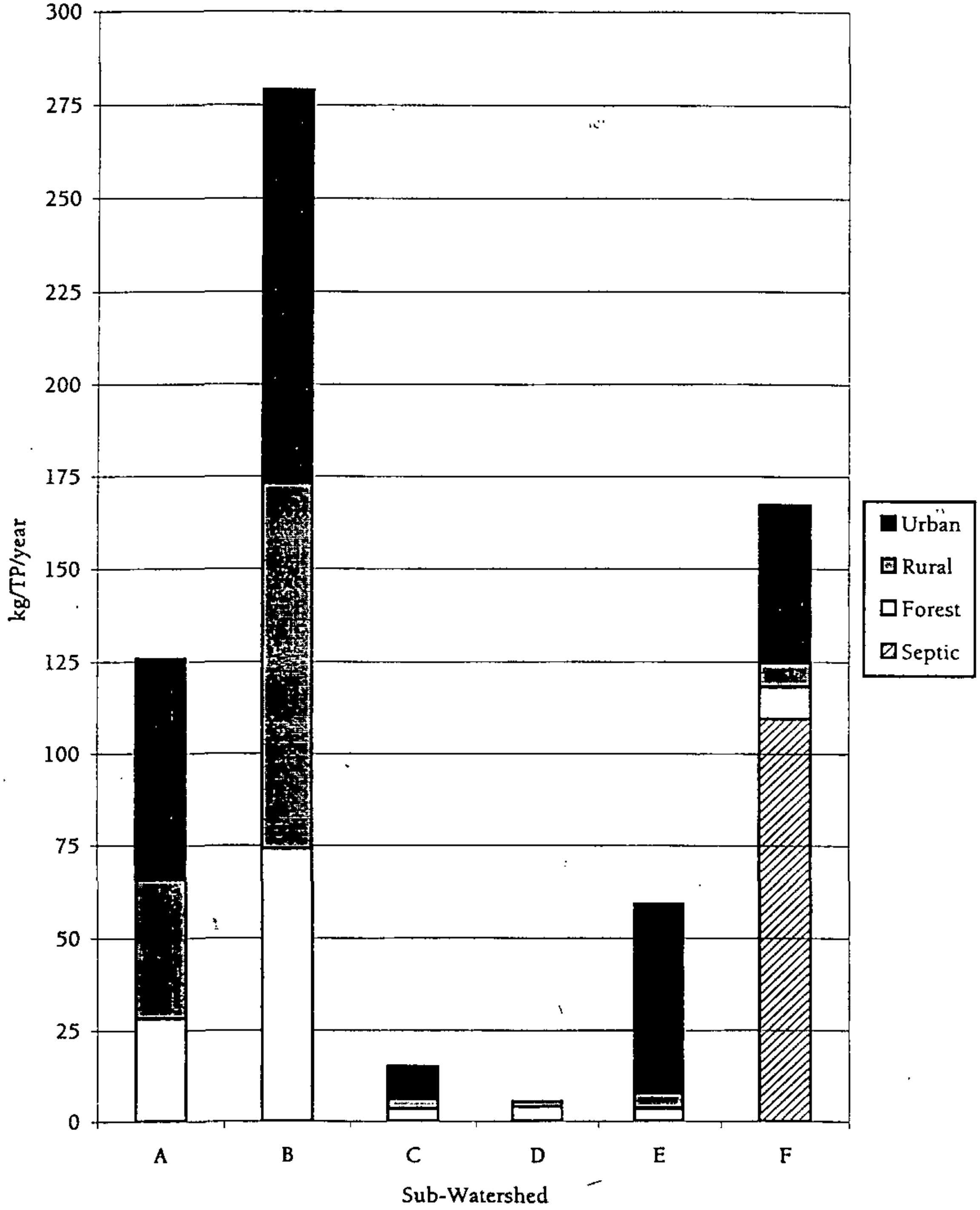
Figure 15: Relative Total Phosphorus Load Per Acre for Each Sub-Watershed



BSC GROUP

Figure 16: Estimated External Total Phosphorus Load for Each Sub-Watershed by Land Use

Total Load to Lake Shirley (including septics) = 653kg/year (approx.)



Sub-watershed B (Catacoonamug Brook) contributes by far the greatest amounts of phosphorus to the lake (279.1 kg/yr.), although its per acre contribution (0.051 kg per acre/yr.) was the second lowest of all sub-watersheds. Conversely, Sub-watershed E was calculated to have by far the highest rate of loading per acre (0.161 kg per acre/yr.), but contributed a relatively moderate total TP load (59.2 kg/yr.). These differences illustrate how land uses affect estimated total loading rates. The high percentage of rural and forested land in sub-watershed B results in a lower relative loading rate per acre. The high total phosphorus loading from sub-watershed B is largely a function of its size. Although sub-watershed B contributes 42.8% of the total external TP load to Lake Shirley, it comprises approximately 61% of the lake's watershed. The high estimated relative loading rate per acre from sub-watershed E is due to the large percentage of its area that is in mining land use (which is considered urban land in the model) at the Keating site.

Sub-watershed A (Easter Brook), which comprises approximately 21% of the total watershed area, had the second highest estimated external TP loading (125.9 kg/yr.). The estimated per acre loading rate from Easter Brook sub-watershed (0.065 kg per acre/yr.) was slightly higher than that of the Catacoonamug Brook sub-watershed (0.051 kg per acre/yr.), which was consistent with the field data collected by BSC.

Sub-watershed F, the proximal watershed of Lake Shirley, was assessed for loading rates from (1) surface water runoff and (2) septic system inputs. The estimated per acre surface water loading rate (0.103 kg per acre/yr.) was the second highest of the six sub-watersheds, yielding a moderate total load (57.8 kg/yr.). When the estimated subsurface contribution from septic systems (109.5 kg/yr.) are also considered, sub-watershed F becomes the second largest contributor of TP. Although sub-watershed F comprises only 10% of the Lake Shirley watershed, the combined TP load from surface runoff and septics accounts for roughly 25% of the lake's total external phosphorus budget.

Sub-watershed C and sub-watershed D both are estimated to contribute insignificant TP loads to Lake Shirley. Both sub-watersheds are relatively small percentages of the watershed area. As expected from an area that is almost entirely forested, sub-watershed D had the lowest relative loading rate (0.03 kg per acre/yr.).

Modeling Uncertainty Discussion:

> "Uncertainty is a state or condition of incomplete or unreliable knowledge. It is ubiquitous in planning and in environmental analysis and is present in most scientific endeavors. Uncertainty also exists in all scientific projections of future conditions because of the nature of induction" (Reckhow and Chapra, 1983).

As stated previously, the DEP phosphorus loading model was validated by an independent data set and found to be accurate within about 36% (Mattson and Isaac 1999). Despite the uncertainties associated with scientific predictions, the DEP model can still serve as a useful starting point for estimating the total phosphorus loading to a lake. Specifically, Mattson and Isaac (1999) state that "as in any environmental model, it should be considered a simple tool to be used, along with other local information and best professional judgement to devise a reasonable management plan and should not be considered as an equal substitute for data collected in the field."

While the DEP model originally appeared to overestimate the TP loading to Lake Shirley, BSC calibrated the model using field data collected from the major tributaries to Lake Shirley. While uncertainty associated with the modeling parameters, relationships, equations, and results, as well as uncertainty associated with the collection and laboratory analysis of water quality samples undoubtedly exists, BSC feels that the model is an important tool that can be used to determine the relationship of TP loading on both a land use and a sub-watershed basis.

1.5 Nutrient Loading Control Alternatives

Watershed management techniques that are used to reduce nutrient loading can be grouped into the following two general categories: (1) transport mitigation techniques and (2) source reduction techniques. Transport mitigation involves techniques which detain, infiltrate or treat flows in the watershed, preventing the transport of nutrients from watershed sources to a receiving water body such as Lake Shirley. Examples of transport mitigation include:

- stormwater detention or infiltration basins
- street drainage improvements (i.e. catch basins with deep hoods and sumps)
- street sweeping/catch basin cleaning
- vegetated treatment swales
- chemical phosphorus inactivation (alum injection system)

Source reduction techniques, quite simply, are techniques which reduce or eliminate the primary sources of nutrients. Some examples of source reduction include:

- replacement of sub-standard or failing septic systems
- replacement of on-site septic systems with sanitary sewers
- reduction in lawn fertilizer use
- implementation of agricultural best management practices (BMPs) designed to limit direct runoff from croplands and livestock areas
- implementation of zoning and land use planning controls to condition new development
- installation of bank/slope stabilization to control sediment loading

In order to evaluate the opportunities for nutrient loading reduction with traditional stormwater detention best management practices (BMPs), it was necessary to (1) conduct an engineering assessment of stream flows and total phosphorus concentrations and (2) evaluate the potential areas for siting BMPs. Since phosphorus is typically the "limiting" nutrient for plant and algae growth in freshwater lakes, the engineering assessment focused on designs to reduce the in-stream total phosphorus concentrations. Since over 90 percent of the surface water flows to Lake Shirley come from Catacoonamug Brook (62%) and Easter Brook (29%), BSC focused the engineering assessment on these two tributaries.

<u>Catacoonamug Brook Sub-watershed</u>

Nutrient Concentrations: At station B-3, on the first wet weather sampling date (July 1st), the water quality data show that there was an abnormally high total phosphorus (TP) and ammonia-nitrogen concentration. A dairy farm is located on the adjacent uphill slopes that are directly tributary to station B-3. However, there is no corresponding abnormally high TP or ammonia-nitrogen concentration at station B-2 (the next downstream sampling station). It is possible that there may have been some type of contamination that was part of the sample collected at station B-3. Therefore, the July 1st sampling data for both TP and ammonia-nitrogen concentrations at station B-3 were not used in the analysis. The elimination of the July 1st sampling data for station B-3 seems to reduce the value of testing at this station as this leaves only one set of sampling data (September 10th) for analysis.

At station B-1, on the second dry sampling date (July 30th), the water quality data show that there was an abnormally high TP concentration while the ammonia-nitrogen concentration data shows a relatively small increase. There is no logical explanation that can be offered to explain the extremely high increase in TP concentration and relatively small increase in ammonia-nitrogen concentration. Therefore, the July 30th sampling data at station B-1 for both TP and ammonia-nitrogen was not used in the analysis.

When the results for each sampling station are averaged for a dry period of collection vs. a wet (recent rainfall event) period of collection, there does not seem to be any significant increase in nutrient concentrations due to wet weather.

When the results for each station are averaged for total concentration the only pattern seems to be that the final discharge point (station B-1) has the lowest level of concentration of any of the stations in the watershed.

Catacoonamug Brook Streamflow: Flows at the sampling stations were proportioned by subcatchment areas using the 10-year flow value of 380 cubic feet per second (cfs) at station B-1, which was obtained from the Flood Insurance Rate Map (FIRM) Flood Study. BSC attempted to verify the flows from the FIRM Flood Study using the USGS Wandle Method to calculate stream watershed runoff for different storm events. The flows generated using the Wandle Method did not agree with the values from the FIRM Flood Study. Thus, BSC estimated the flow for a 2-year frequency storm event by using the proportion between the Wandle Method 10-year and 2-year frequency storms and proportioning that by the subcatchment area and the FIRM 10-year frequency storm event at each collection station.

The one-year frequency storm event flow was estimated by proportioning the 2-year frequency storm event flow, based on the ratio of the 24-hour rainfall for the 2-year frequency storm (estimated to be 3.0 inches) to the 1-year frequency storm (estimated to be 2.6 inches).

The stream flow calculations for the 2-year and 1-year frequency storm events are provided below.

Sample point	Individual Tributary Area (acres)	Individual Tributary Area (sq. mi.)	Cumulative Tributary Area (sq. mi.)	FIRM Q10 (cfs)	FIRM Q10 (cfs)	FIRM Q2 (cfs)	1 Yr. Rainfall / 2 Yr. Rainfall Q1 (cfs)	M & E Base Flow (cfs)
B-5	758	1.18	1.18		53	28	24	1.15
B-4	897	1.40	2.59		115	61	53	2.52
B-3	1,953	3.05	3.05		136	72	62	2.97
B-2	1,469	2.30	7.93		354	187	162	7.72
B-1	375	0.59	8.52	380	380	200	174	8.29
Total	5,452	8.52						

M&E Weighted Average Flow
(base flow)= 8.29 cfs
Estimated 1-Year 24-hour rainfall = 2.6 inches
Estimated 2-Year 24-hour rainfall = 3.0 inches

	USGS Wandle Method				
	Q10=72.12A^0.660		Q2=36.30A^0.682		FIRM
	A (sq. mi.)	Q10 (cfs)	A (sq. mi.)	Q2 (cfs)	Q2 (cfs)
BSC	8.52	297	8.52	156	200
FIRM	8.81	303	8.81	160	201
M & E	9.30	314	9.30	166	201

The weighted average flow from the 1988 Lake Shirley study by M&E was used as a base flow to evaluate possible treatment BMPs in the study area.

Easter Brook Sub-watershed

Nutrient Concentrations: The concentrations for both total phosphorus (TP) and ammonia-nitrogen were reviewed. There are no stations or samples which showed abnormally high TP or ammonia-nitrogen concentrations. TP values ranged from below detection level to a high of 0.08 mg/l. The range of ammonia-nitrogen values is from below detection level to a high of 0.5 mg/l.

When the dry-weather sampling results were compared to the wet-weather sampling results, a distinct increase in the TP concentration for the wet weather sampling was identified. This is typical of non-point source pollution. The wet weather sampling water quality data did not show a similar increase in ammonia-nitrogen concentration data.

When the results for each station are averaged for total concentration, no clear pattern appears.

Easter Brook Streamflow: Flow at the sampling station A-3 was based on published flow data from Gaged Station No. 01095800, located on Easter Brook off of Pierce Street in North Leominster (see Table 1-8 below). The Wandle Method was used for a trial calculation and the gaged value was greater then the calculated value. An additional calculation was made using the FIRM 10-year flow at sample Station B-1 and proportioning it by area. This value was even less than the one calculated using the Wandle Method.

Table 1-8: Selected Basin and Flood Characteristics for Gaged Stations

EASTERN REGION							Year:	2	5	10	25	50	100
Row No.	Station No.	Station Name	Station location: Latitude (decimal degrees)	Station location: Longitude (decimal degrees)	Drainage area (mi²)	Years of observed peak flow record	Years for historic peak adjustment*	Peak discharge from station frequency curve, in cubic feet per second, with the indicated exceedance probability: 0.5	0.2	0.1	0.04	0.02	0.01
1	01073600	Dudley Brook Near Exeter, NH	42.9936	71.0233	4.97	13	0	144	228	297	404	489	609
2	01093800	Stony Brook Tributary Near Temple, NH	42.8600	71.8333	3.60	12	0	136	198	246	315	373	437
3	01095200	Houghton Brook Near Oakdale, MA	42.4158	71.8033	0.89	12	0	20	26	31	38	43	49
4	01095800	Easter Brook Near North Leominster, MA	42.5500	71.7100	0.92	11	0	36	57	75	104	129	159
5	01096000	Squannacook River Near West Groton, MA	42.6300	71.6600	64.9	26	0	1290	1910	2410	3140	3770	4470
6	01097200	Heath Hen Meadow Brook at Stow, MA	42.4500	71.5000	3.89	11	0	45	73	98	137	173	216

Flows at the collection points were proportioned by subcatchment areas using the flow data Gaged Station No. 01095800. The one-year frequency storm event flow was estimated by proportioning the 2-year frequency storm event flow, based on the ratio of the 24-hour rainfall for the 2-year frequency storm (estimated to be 3.0 inches) to the 1-year frequency storm (estimated to be 2.6 inches).

The stream flow calculations for the 2-year and 1-year frequency storms are provided below.

Sample point	Individual Tributary Area (acres)	Individual Tributary Area (sq. mi.)	Cumulative Tributary Area (sq. mi.)	Wandle Method Q10 (cfs)	MHD Q10 (cfs)	MHD Q2 (cfs)	1 Yr. Rainfall / 2 Yr. Rainfall Q1 (cfs)	M & E Base Flow (cfs)
A-5	119	0.19	0.19	0	14	7	6	0.25
A-3	498	0.78	0.96	49	75	36	31	1.32
A-4	487	0.76	0.76	39	59	28	25	1.04
A-2	559	0.87	2.60	132	202	97	84	3.56
A-1	141	0.22	2.82	143	219	105	91	3.86
	1,804	2.82		143				

M&E Weighted Average Flow (base 3.86 cfs flow)=
Estimated 1-Year 24-hour rainfall = 2.6 inches
Estimated 2-Year 24-hour rainfall = 3.0 inches
Mass Highway Department Design Manual Table 10.4
Gaging Station at A3 with 0.96 sq.mi.
& Q10 = 75 cfs
Q2 = 36 cfs

	USGS Wandle Method			
	Q10=72.12A^0.660		Q2=36.30A^0.682	
	A (sq. mi.)	Q10 (cfs)	A (sq. mi.)	Q2 (cfs)
BSC	2.82	143	2.82	74

Flow Based on Area			
B Area =	8.52 sq. mi.	Q10 =	380 cfs
A Area =	2.82 sq. mi.	Q10 =	126 cfs

The weighted average flow from the 1988 Lake Shirley Study by M&E was used as a base flow to evaluate possible treatment best management options in the study area.

Detention Best Management Practices (BMPs)

The Massachusetts DEP Stormwater Management Policy (1996) states that "Generally, most particulates settle within the first 12 hours of detention; however, additional time is required to settle finer particulates. Twenty four hours is the minimum detention time necessary for optimal pollutant removal."

The first type of detention BMP considered in this analysis was the use of a shallow depression to act as a forebay or water quality treatment swale. An initial review of the Catacoonamug Brook and Easter Brook sub-watershed flow rates determined that there was no available storage area within the watershed that could reasonably treat even the 1-year frequency storm. The large storage areas required for treatment were not available due to private land holdings, topographic constraints and the presence of protected wetland resource areas. Treatment of the estimated stream base flows were then investigated. The required storage volume for 24 hours (as well as for 12 hours) of holding time were still not available within these sub-watersheds.

BSC reviewed water column nutrient settling data and TP removal rates for detention times, as shown in Table 1-9 and in Figure 17.

Table 1-9: TP Removal Rates by Detention Time

DETENTION TIME (hours)	TOTAL PHOSPHORUS REMOVAL (%)
24	49
12	45
6	35
2	23

(Reference: Figure 4.2-1: Results of settling column study on urban runoff from Protecting Water Quality in Urban Areas (OWML, 1983)

Figure 17: Results of Settling Column Study on Urban Runoff

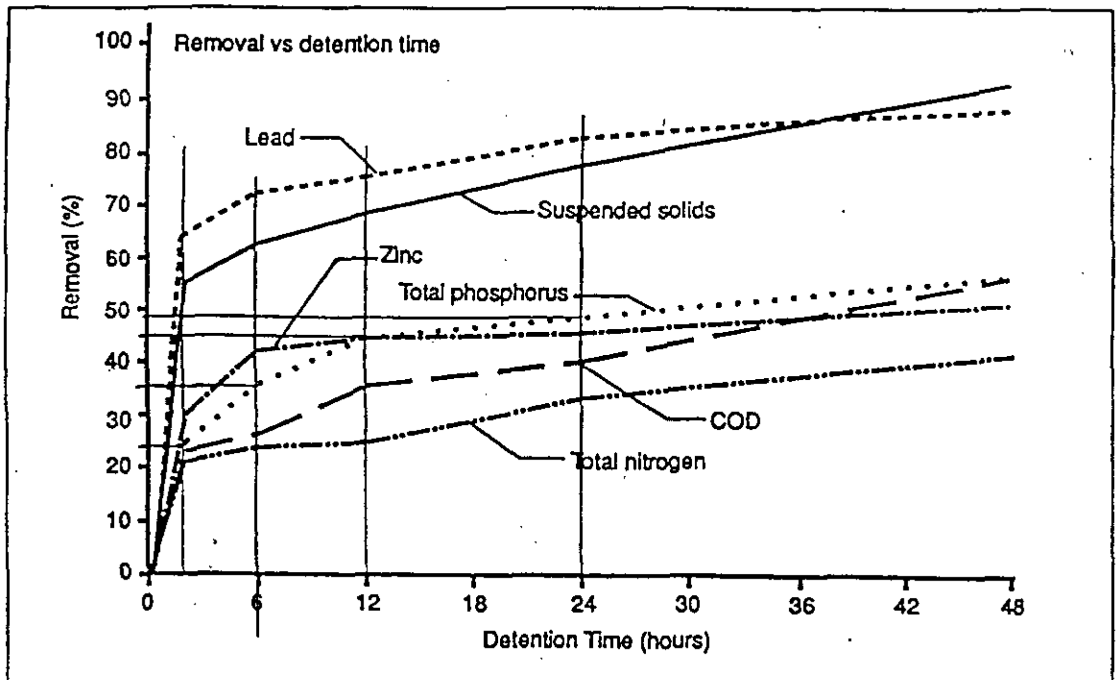


Figure 4.2-1: Results of settling column study on urban runoff

Source: OWML, 1983

FROM: "Protecting Water Quality in Urban Areas"
(Best Management Practices for Minnesota)

Based on the water column nutrient settling data, BSC determined the storage volumes that would be required to achieve a six-hour holding time (Refer to Tables 1-10 and 1-11). These volumes are physically available at a number of the study station locations if private easements or land purchases can be obtained.

Table 1-10: Catacoonamug Brook Required Storage for 6 Hours of Holding Time
(Note: Storage for 6 hrs. of holding time = 1.15cfs x 60 sec/min x 60 min/hr x 6 hr/day = 24,896 cf)

Site Location	Q1 6-Hr Storage (cf)	2-ft deep (sq. ft)	Horizontal Dimensions	Qbase 6-Hr Storage (cf)	2-ft deep (sq. ft)	Horizontal Dimensions
B-5	521,822	260,911	1,000 x 260	24,896	12,448	250x50
B-4	1,139,333	569,667		54,356	27,178	300x100
B-3	1,344,482	672,241		64,144	32,072	300x100
B-2	3,495,103	1,747,551		166,748	83,374	400x200
B-1	3,753,260	1,876,630		179,064	89,532	450x200

Table 1-11: Easter Brook Required Storage for 6 Hours of Holding Time
(Note: Storage for 6 hrs. of holding time = 0.2546 cfs x 60 sec/min x 60 min/hr x 6 hr/day = 5,500 cf)

Site Location	Q1 6-Hr Storage (cf)	2-ft deep (sq. ft)	Horizontal Dimensions	Qbase 6-Hr Storage (cf)	2-ft deep (sq. ft)	Horizontal Dimensions
A-5	129,978	64,989	650x100	5,500	2,750	100x30
A-3	673,920	336,960	1,100x300	28,516	14,258	150x100
A-4	531,927	265,964	900x300	22,508	11,254	120x100
A-2	1,816,416	908,208		76,859	38,430	380x100
A-1	1,970,424	985,212		83,376	41,688	420x100

The simplest configuration for this type of BMP is that of a depressed area in the upland area adjacent to the streams, which is graded to be below the flood elevation. This design would only intercept and treat the portion of the stream that flowed over the depression. Considering the large volume of flow in Catacoonamug Brook and Easter Brook, this design would be almost useless in providing any significant reduction in phosphorus loading.

A more effective configuration would be to provide a low weir (dam) across the stream channel to divert the stream base flow into the depressed area. This would provide some additional treatment and still allow the storm flows to continue downstream over the low weir. This water quality swale or forebay would have to have a well-developed bed of hydrophytic vegetation to provide a screen that would provide both physical protection and soil stabilization. This would aid in preventing settled particulates from being re-suspended into the water column. The flow velocity at any area where this approach is considered would have to be confirmed to ensure that permissible velocities are not exceeded. The weir would cause an increase in the flood elevations that would occur at each site. Therefore, upstream impacts would have to be evaluated. Detailed, ground-truthed topographic survey data would have to be obtained to confirm the impact.

However, to achieve a more effective and meaningful treatment, at the least, the base flow as well as the "first flush" of storm runoff needs to be intercepted. The first flush is a flow that is greater than the base flow but less than the estimated one-year frequency storm event. Any increase in the flow will reduce the effectiveness of the proposed water quality swales, due to the limited storage volume that is available. In addition, in order achieve this flow diversion, the weir would have to be set at a higher elevation to divert the higher flow and a greater storage volume would be required.

Overall, because of the size of the Easter Brook and Catacoonamug Brook sub-watersheds and the significant flows that come from them, detention methods are not feasible. Only major damning projects requiring large amounts of space are really likely to achieve any effective treatment in the removal of Total Phosphorus. Long detention times, which result in large volumes of water with reduced discharge rates, are necessary to provide meaningful reduction in nutrient levels.

It is important to note that both Easter Brook and Catacoonamug Brook have extensive wetland systems in their downstream reaches that provide significant flood storage and nutrient uptake. The incremental benefits provided by additional engineered detention capacity would be relatively minor. It is also important to note that the type of detention treatment that has been discussed above is based on the settlement of particulate matter to which non-soluble phosphorus has been adsorbed. Because phosphorus is 40% to 60% soluble, this limits the effective treatment to be a function of the total stream flow that can be intercepted, which depends on the storage volume and detention time that can realistically be provided.

Another concern is the impact that raised water levels would have on the existing plant communities in the adjacent upstream wetland areas. In some areas, the increased water levels required for treatment would flood private property, raising legal issues and potentially being considered a "taking" of private property. Property rights or easements would be necessary to provide locations for the treatment facilities. Approvals would have to be obtained from the local Conservation Commission, the state Department of Environmental Protection and local owners and abutters. All of these concerns would have to be fully addressed before any treatment could be implemented.

In the unlikely event that the above constraints to providing in-stream detention treatment along Easter Brook and Catacoonamug Brook can be met, construction of a typical flow detention system would cost in the range of $170,00 to $200,000.

<u>Alum Treatment</u>

In-stream chemical treatment involves the dosing of stream flows with liquid alum to bind phosphorus and coagulate sediments to promote settling. This process, also known as alum injection, permanently binds phosphorus with an alum, making it unavailable for biological uptake by algae. This type of treatment, which is commonly used to process drinking water, has been used successfully to reduce nutrient loading from streams where other BMPs were not feasible. Depending on flow rates and in-stream nutrient concentrations, phosphorus removal rates of 50-90% have been reported. Variations in treatment effectiveness can occur due to fluctuations in stream water quality during the course of a storm. To mitigate for potential pH fluctuations caused by this treatment, use of an additional buffering agent is usually required in water bodies with low alkalinity, such are typically found in New England.

An alum injection system could be potentially sited at or near the Easter Brook inlet or Catacoonamug inlet to Lake Shirley. Each system could be automated with a solar-powered mechanism to provide alum injection based on anticipated flow rates and phosphorus concentrations of each stream. At either site, a secure facility would be required to house the equipment, including the alum injection system, control module. Mixing equipment may also be required to maximize water contact with the alum. One or more tanks would also be needed to contain the alum and binding agents.

An alum injection system from Sweetwater Technology would cost approximately $75,000, with anticipated annual maintenance and supply costs estimated at $5,000 per year.

An alternative method of phosphorus inactivation is in-lake alum treatment. This approach is usually most beneficial at deep lakes with a long retention time (the amount of time it takes for the lake to refill with new water). Both the longevity and effectiveness of in-lake alum treatment are less at lakes with relatively short retention times, such as Lake Shirley. Although alum will quickly flocculate phosphorus out of the water column in such lakes, the "clear" waters are flushed out and may be replaced by nutrient-rich waters from inlet streams.

In a shallow, weakly stratified lake such as Lake Shirley, in-lake alum dosing would involve using boats to uniformly dose the entire lake with alum. Because Lake Shirley has relatively low alkalinity, the use of a more expensive base compound such as sodium aluminate would be necessary to prevent harmful fluctuations in pH. Based on communications with Aquatic Control Technology, the cost of this type of treatment at Lake Shirley would be approximately $300 to $400 per acre, for a total cost of approximately $100,000 to $140,000 for a one-time treatment. Due to the relatively short retention time of Lake Shirley, the benefits of this type of alum treatment are not likely to extend beyond one year. Considering the high cost and poor anticipated longevity of benefits, this method of alum treatment is not recommended.

Source Reduction

Source reduction techniques generally apply to all parts of the Lake Shirley watershed, but will be relatively more effective in the areas closest to the lake. Source reduction can be particularly effective in the proximal watershed of lakes, where runoff reaches the lake more directly and there are relatively fewer natural attenuation mechanisms (such as wetlands) filtering runoff on its way to the lake. Several options for source reduction are summarized below:

- Testing septic systems around Lake Shirley and those adjacent to tributary wetlands and stream channels would aid in confirming possible pollution from this source. An engineering evaluation including a dye test would cost approximately $200 to $250 per home. Testing all of the 224 homes adjacent to Lake Shirley would cost a total of approximately $45,000 to $55,000.

- Upstream farms should be more closely investigated as possible sources of pollutants. Vegetated buffer strips should be developed between streams and all crop fields and livestock grazing areas. Interception swales that are designed to act as water quality treatment BMPs are another treatment practice that could be applied to this source.

- Existing street drainage can be enhanced to provide additional treatment. In areas where flow from adjacent drainage structures are directed into existing catchbasins, this flow source should be removed by collecting the flow in individual catchbasins with a separate drain manhole system. This will reduce the re-suspension of previously settled particulates. The estimated cost for each new drain manhole is $2,000.

- Existing catchbasins can be replaced with deep sumps (minimum 4-feet deep, below outlet invert) and hooded outlets. Replacing existing catch basins, including the removal of existing units, should cost around $3,000 per unit. Although less effective at providing nutrient reloading reduction, a less expensive option is to retro-fit existing catchbasins with new hooded outlets at a cost of roughly $300 per unit. To maintain treatment effectiveness, catch basins should be vacuum cleaned at least annually. Cleaning with a clamshell bucket does not adequately remove sediments and is not recommended.

- Many of the roads in the tributary watershed use 'country drainage.' That is, the street runoff sheet flows into roadside ditches. Excavating to increase the cross section of the ditch can enhance the treatment effectiveness of these ditches. Loam and seed can then be placed with check dams to make the ditch function as a vegetated water quality treatment swale. The cost of this BMP will vary, depending on if it is necessary to gain easements or purchase land to create the swale. Typically, at least a 20 to 30 foot wide area, adjacent to the road shoulder, is needed to provide adequate treatment area.

- All new developments that are in the Lake Shirley watershed should be required to meet all the requirements of the state Stormwater Management Policy standards. This should apply even to those projects that do not require a filing of a Notice of Intent under the Wetland Protection Act. To be assured that the Stormwater Management Policy standards apply to all new developments, the local Rules and Regulations under the Subdivision Control Law would have to be modified to incorporate these standards.

- Cluster or Planned Unit Development zoning bylaws and regulations should be emphasized. With proper incentives, the amount of impervious pavement can be significantly reduced, open space in buffer zones can provide additional overland protection and treatment. This would require zoning by-law modification. Again, the Stormwater Management policy standards would have to be included as part of the required design standards that any cluster or Planned Unit Development would have to meet. The Planning Board can also enact stormwater management requirements that apply to all proposed development in the Lake Shirley watershed.

- Local Conservation Bylaws that reduce or restrict construction in the buffer zone to wetland resource areas can also provide additional protection by placing possible pollutants at a greater distance from the streams and their tributary wetlands.

2.0 Dredging Feasibility Evaluation

2.1 Review of Existing Data

To assist in the evaluating the feasibility of conducting a dredging program at Lake Shirley, BSC reviewed existing data on lake bathymetry, hydrology and sediment depths from a variety of sources. Of particular use was the 1988 Diagnostic/Feasibility (D/F) Study on Lake Shirley (Metcalf and Eddy), which included detailed information on sediment depth contours, collected during a survey conducted in August 1986. This survey calculated that sediment depths in Lake Shirley ranged from zero to 12 feet (with depths of 2 to 4 feet over most of the lake), and estimated the total volume of soft sediment at 1,560,000 cubic yards. Soft sediment depths were deepest (12 feet) in the deep-hole area in southeast basin of Lake Shirley, which existed as a natural pond before the present water body was impounded.

Due to the relatively short amount of time elapsed since the D/F study was conducted, BSC did not anticipate dramatic changes in the Lake Shirley sediment depth contours. However, some increase in soft sediment was expected, due to the ongoing decomposition of aquatic plants and sedimentation from watershed sources.

2.2 Sediment Sampling Program

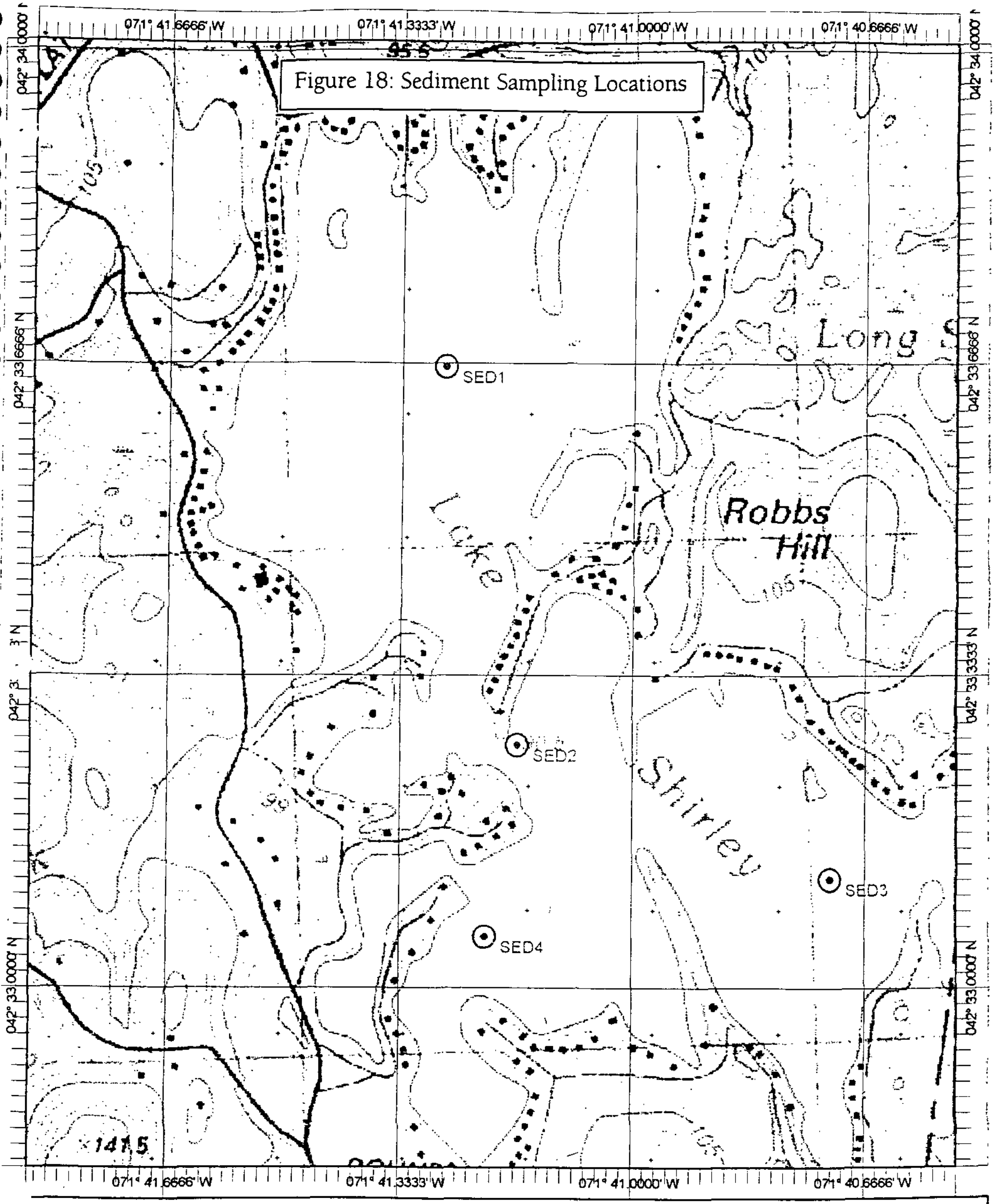
<u>Sediment Sampling Methodology</u>

In order to (1) obtain information on sediment chemical and physical properties, and (2) measure soft sediment depths in several key locations, borings were developed at four locations in the lake (see Figure 18). Water depth at each sampling location was measured with a boat-mounted sonar instrument. Sediment samples from three of the borings (Sed-1, Sed-2, and Sed-3) were obtained for laboratory analysis. The sediment sampling sites are described as follows:

- Sed-1: Located at the deep hole in the center of the shallow northern basin, roughly centered between the Catacoonamug Brook inlet and the narrow channel connecting the northern basin to the middle basin.
- Sed-2: Located just south of the narrow channel connecting the northern basin to the middle portion of the lake.
- Sed-3: Located in the southeast quadrant of the southern basin, southwest of the Beautiful Lake Shirley Beach area.
- Sed-4: Located in the southwest quadrant of the middle section of the lake.

The sampling locations were selected to provide data from each basin of the lake, in areas that were considered potentially suitable for dredging. Each of the sampling stations had a water depth of less than 10 feet and were in locations where sediment accumulation has the potential to interfere with recreational boating or swimming. In general, a minimum of 10 feet of water depth is necessary in order to prevent the growth of rooted aquatic plants due to the lack of sunlight penetration to the sediments. Accordingly, sediment sampling was not conducted at the Lake Shirley "deep hole" in the southern basin (35 ft. deep), where plant growth is light-limited and dredging would yield the fewest benefits.

Figure 18: Sediment Sampling Locations



Name: AYER
Date: 8/12/99
Scale: 1 inch equals 800 feet

Location: 042° 33.4095' N 071° 41.1975' W
Caption: TGB Vibrocore Locations

Sediment borings were conducted on June 6, 1999, using boat-mounted, motorized vibrocoring equipment. The vibrocoring unit was driven into the soft sediment until refusal, and a core sample was taken at each site. Each core sample was individually deposited in a large plastic bucket and mixed for uniformity to create a composite that was representative of the entire soft sediment profile. Samples were then collected in glass bottles, stored on ice, and delivered immediately to Microbac Laboratories, Inc. (Clinton, MA) for analysis. In accordance with requirements of the Section 401 Water Quality Certification for Dredging Projects, each sample was analyzed for the parameters listed below in Table 2-1. A complete listing of each polynuclear aromatic hydrocarbon (PAH) compound and each polychlorinated biphenyl (PCB) arochlor analyzed is included in the Sediment Analysis Results (Table 2-4).

Table 2-1: Sediment Analysis Parameters

Metals	Organics	Grain Size (%)	Other
Arsenic	PCB's	<5 μm	Total Solids
Cadmium	PAH's	5-10 μm	
Chromium	Total Petroleum Hydrocarbons (TPH)	10-25 μm	
Copper		25-50 μm	
Lead		50-100 μm	
Mercury		>100 μm	
Nickel			
Zinc			

<u>Sediment Sampling Results</u>

In order to determine the suitability of the sediments in Lake Shirley for various upland disposal options, sediment borings were conducted and samples were analyzed for chemical and physical parameters required to file a Section 401 application for dredging. Results of these analyses are summarized below.

Sediment Borings:

A summary of the sediment boring results at each sampling location is given below in Table 2-2.

Table 2-2: Sediment Boring Summary

Sampling Station	Water Depth (feet)	Approx. Sediment Depth (feet)	Notes:
Sed-1	8.0	8.0	Very fine, organic silt overlying peat
Sed-2	9.0	4.0	Very fine, organic silt overlying sand/gravel
Sed-3	8.5	5.0	Very fine, organic silt overlying peat ***Stumps in area***
Sed-4	3.5	9.0	7 ft of penetration after approx. 2 ft. of extremely fine, organic silt

The soft sediments in sampling stations Sed-1, Sed-3 and Sed-4 can be characterized as having several feet of extremely flocculent organic muck/silt, overlying a more consolidated peat layer. Sampling station Sed-2 exhibited a layer of extremely flocculent organic silt/muck overlying sand/gravel. Due to sample compaction and anticipated inefficiencies in capturing the extremely flocculent top-layer sediments, each core sample somewhat underrepresented the top-layer sediments as a portion of the total soft sediment profile.

The soft sediment depths recorded by BSC were several feet deeper than those reported by the 1986 Metcalf and Eddy (M&E) survey. Although some of this increase may be attributed to a real accumulation of sediment, it is also likely that the differences can be attributed to differences in the sampling methods used. In the 1986 study, sediment depths were measured by hand-pushing a metal rod to refusal. It is likely that refusal was consistently reached at a lesser depth than that achieved by the motorized vibrocoring device used by BSC. At the BSC sampling locations, the depth of the top layer of organic muck was roughly consistent with the total soft sediment depth reported by M&E. It seems possible that the M&E method did not measure below the top layer of muck, and that the BSC method included the underlying, more consolidated peat layer. It should also be noted that, despite near-drought conditions and a below average lake level at the time of sampling, the water depths measured in June 1999 by BSC at each sediment sampling site were roughly equal to those measured in the 1986 bathymetric survey by M&E. This further indicates an insignificant increase in soft sediment depths since 1986.

For the purposes of assessing dredging feasibility, as discussed below in Section 2.4 (Dredging Method Assessment), BSC assumed that dredging would focus primarily on removal of the nutrient-rich top-layer of organic muck/silt. Removal of the top two feet of sediment over seventy percent of the lake area would result in a total removal of approximately 807,000 cubic yards.

Sediment Physical Analysis Results:

The sediment grain size analysis, summarized below in Table 2-3, indicates that Lake Shirley sediments are comprised primarily of extremely fine, silty organic material. The composition of samples Sed-1 and Sed-3 were very similar, reflecting a similar soft sediment profile of organic muck overlying a peat layer. The composition of Sed-2 was coarser, reflecting a sediment profile of organic muck overlying sand/gravel. Because sediment sampling equipment is more efficient at capturing consolidated material than fine, flocculent material, each analysis somewhat overestimates the average grain size of the sediment profiles. This is a result of sampling losses anticipated from the first several feet of highly flocculent sediment.

Because of the extremely organic, mucky composition of Lake Shirley sediments, some processing is likely to be required to make the sediments suitable for most upland disposal options. Most potential uses, including re-use as daily cover at landfills, and topsoil for agriculture, sporting fields or other types of land development, would require mixing with a more coarse material (sand) to provide sufficient structure. This is particularly true for the first several feet of sediment, which is the recommended target for dredging. The need for sediment processing would add to the ultimate disposal cost, limit the range of potential options for lower-cost disposal, and limit the potential market for sale of the dredged material.

Table 2-3: Sediment Physical Analysis Results

	Sed-1	Sed-2	Sed-3
Total Solids (%)	11.4	19.6	10.6
Grain Size (%):			
<5µm	81	51	76.5
5-10µm	8	19	13
10-25µm	8	22	8
25-50µm	1	7	1
50-100µm	0	0	0
>100µm	2	1	0.5

Sediment Chemical Analysis Results:

The concentrations of metals, PAH's, and PCB's (see Table 2-4 below) tested well within acceptable levels for dredging permitting. These results indicate levels low enough to be considered Category One, the cleanest classification of dredged material under Massachusetts' regulations (314 CMR 9.07). This classification allows for the widest range of upland disposal and re-use options for dredged materials.

The level of Total Petroleum Hydrocarbons (TPH) found at station Sed-1 (840 mg/kg) and station Sed-3 (670 mg/kg) are well within the acceptable levels for disposal at lined landfills, but are high enough to trigger the need for additional testing in order to meet the standards required for beneficial upland re-use of sediments. It is quite common to find moderate levels of combustion byproducts in lakes receiving runoff from a partially urbanized watershed. The levels found in Sed-1 and Sed-3 are not unusual for lake sediments. Further, these results do not necessarily mean that the sediments exceed the Category One thresholds required by the Massachusetts Contingency Plan (MCP)/Chapter 21E Method 1 Standards (310 CMR 40.0000) for S-1 soils and GW-1 groundwater. If upland re-use of sediments is proposed and TPH concentrations exceed 200 mg/kg, DEP requires a more detailed analysis of petroleum hydrocarbon fractions. Although the MCP Method 1 standard for many TPH fractions is much higher than 200 ppm, the standard for C5 through C8 aliphatic and C9-C22 aromatic hydrocarbons is 200 ppm or lower. Therefore, additional testing for these TPH fractions will be required if beneficial upland re-use of Lake Shirley sediments is proposed.

Table 2-4: Sediment Chemical Analysis Results

- All results in mg/kg
- BDL=below detection limit

	Sed-1	Sed-2	Sed-3
Metals:			
Arsenic	0.48	0.40	0.62
Cadmium	0.09	0.11	0.09
Chromium	0.041	0.051	0.010
Copper	0.97	2.01	1.68
Lead	1.89	5.64	3.71
Mercury	BDL	BDL	BDL
Nickel	0.69	3.61	BDL
Zinc	4.71	9.83	7.00
Total Petroleum Hydrocarbons	840	173	670
PCB's			
Arochlor 1016	BDL	BDL	BDL
Arochlor 1221	BDL	BDL	BDL
Arochlor 1232	BDL	BDL	BDL
Arochlor 1242	BDL	BDL	BDL
Arochlor 1248	BDL	BDL	BDL
Arochlor 1254	BDL	BDL	BDL
Arochlor 1260	BDL	BDL	BDL
PAH's in Solids			
Naphthalene	BDL	BDL	BDL
Acenaphthalene	BDL	BDL	BDL
Acenaphthene	BDL	BDL	BDL
Fluorene	BDL	BDL	BDL
Phenanthrene	BDL	BDL	BDL
Anthracene	BDL	BDL	BDL
Fluoranthrene	BDL	BDL	BDL
Pyrene	BDL	BDL	BDL
Benzo(a)anthracene	BDL	BDL	BDL
Chrysene	BDL	BDL	BDL
Benzo(b)fluoranthrene	BDL	BDL	BDL
Benzo(k)fluoranthrene	BDL	BDL	BDL
Benzo(a)pyrene	BDL	BDL	BDL
Dibenzo(a,h)anthracene	BDL	BDL	BDL
Benzo (g,h,I)perylene	BDL	BDL	BDL
Ideno(1,2,3-cd)pyrene	BDL	BDL	BDL
Total Volatiles			
Acetone	0.275	BDL	BDL
Acrolein	BDL	BDL	BDL
Acrylonitrile	BDL	BDL	BDL
Benzene	BDL	BDL	BDL
Bromodichloromethane	BDL	BDL	BDL
Bromomethane	BDL	BDL	BDL
Bromoform	BDL	BDL	BDL
2-Butanone	BDL	BDL	BDL
n-Butylbenzene	BDL	BDL	BDL
Bromobenzene	BDL	BDL	BDL
Sec-Butylbenzene	BDL	BDL	BDL
Tert- Butylbenzene	BDL	BDL	BDL
Carbon Disulfide	BDL	BDL	BDL
Carbon Tetrachloride	BDL	BDL	BDL
Chlorobenzene	BDL	BDL	BDL
Chloroethane	BDL	BDL	BDL
Chloroform	BDL	BDL	BDL
Chloromethane	BDL	BDL	BDL
2-Chlorotoluene	BDL	BDL	BDL
4-Chlorotoluene	BDL	BDL	BDL
2-Chloroethylvinylether	BDL	BDL	BDL

- All results in mg/kg
- BDL=below detection limit

	Sed-1	Sed-2	Sed-3
Dibromochloromethane	BDL	BDL	BDL
Dichlorofluoromethane	BDL	BDL	BDL
Dibromomethane	BDL	BDL	BDL
1,2-Dichloroethane	BDL	BDL	BDL
1,1-Dichloroethane	BDL	BDL	BDL
1,3-Dichloropropane	BDL	BDL	BDL
1,2-Dichloropropane	BDL	BDL	BDL
1,2-Dibromomethane	BDL	BDL	BDL
1,2-Dibromo-3-Chloropropa	BDL	BDL	BDL
Trans-1,4-Dichloro-2-Bute	BDL	BDL	BDL
Trans-1,2-Dichloroethene	BDL	BDL	BDL
Trans-1,3-Dichloropropene	BDL	BDL	BDL
Cis-1,2-Dichloroethylene	BDL	BDL	BDL
Cis-1,3-Dichloropropene	BDL	BDL	BDL
2,2-Dichloropropane	BDL	BDL	BDL
1,2-Dichlorobenzene	BDL	BDL	BDL
1,3-Dichlorobenzene	BDL	BDL	BDL
1,4-Dichlorobenzene	BDL	BDL	BDL
Ethylbenzene	BDL	BDL	BDL
1,1-Dichloropropene	BDL	BDL	BDL
2-Hexanone	BDL	BDL	BDL
Hexachlorobutadiene	BDL	BDL	BDL
Iodomethane	BDL	BDL	BDL
p-Isopropyltoluene	BDL	BDL	BDL
Methylene Chloride	BDL	BDL	BDL
4-Methyl-2-Pentanone	BDL	BDL	BDL
Naphthalene	0.008	BDL	BDL
n-Propylbenzene	BDL	BDL	BDL
iso-Propylbenzene	BDL	BDL	BDL
Styrene	BDL	BDL	BDL
1,1,1,2-Tetrachlorethane	BDL	BDL	BDL
1,1,2,2-Tetrachlorethane	BDL	BDL	BDL
Tetrachlorethane	BDL	BDL	BDL
Toluene	BDL	BDL	BDL
Trichloroethene	BDL	BDL	BDL
Trichlorofluoromethane	BDL	BDL	BDL
1,2,3-Trichlorobenzene	BDL	BDL	BDL
1,2,4-Trichlorobenzene	BDL	BDL	BDL
1,1,1-Trichloroethane	BDL	BDL	BDL
1,1,2-Trichloroethane	BDL	BDL	BDL
1,2,3-Trichlorpropane	BDL	BDL	BDL
1,2,4-Trimethylbenzene	BDL	BDL	BDL
1,3,5-Trimethylbenzene	BDL	BDL	BDL
Vinyl Acetate	BDL	BDL	BDL
Vinyl Chloride	BDL	BDL	BDL
Xylenes, Total	BDL	BDL	BDL

2.3 Dredging Method Analysis

Overview

Dredging can be an effective lake management technique to (1) restore lakes which have lost depth due to sedimentation, (2) control excessive macrophyte and algae growth, and (3) reduce seasonal internal nutrient recycling. Lake dredging can be accomplished by either dry or wet excavation. Dry dredging involves either completely or partially draining the lake and removing the exposed sediments with conventional excavation techniques and equipment. Wet dredging at lakes is most commonly accomplished by hydraulic dredging, which involves pumping sediments out of the lake in a wet slurry form. Because Lake Shirley is an impoundment with a dam which allows for a significant drawdown, both conventional dry dredging and hydraulic dredging are possible. The feasibility of each technique is discussed below.

In some cases, the primary goal of lake dredging is simply to restore or increase lake depth. Generally, the design goals of such projects are fairly straightforward, and are focused on dredging to depths that are adequate for boating or swimming. At Lake Shirley, dredging feasibility is being assessed primarily in response to water quality degradation associated with nuisance growth of macrophytes (rooted aquatic plants) and algae.

Macrophyte Control

There are two methods to control macrophyte growth by dredging. The first requires dredging to a depth which limits sunlight penetration to the sediments, thereby inhibiting or severely reducing the growth of rooted aquatic plants. In Lake Shirley, depths of at least 10 feet of water would probably be necessary before light would become limiting for plant growth. Based on the 1986 bathymetric survey, approximately 84% of Lake Shirley (297 acres) is less than 10 feet deep, and therefore potentially suitable for rooted plant growth. However, 34% of the lake (120 acres) is between 8 and 10 feet deep, which means that light-limiting conditions could be created over this portion of the lake by dredging the first two feet of sediment. This amount of dredging would result in a total of 50% of the lake area (177 acres) having a depth of greater than 10 feet. For comparison, if only one foot of sediment was removed, only an additional 5.5% of the lake (19.5 acres) would be made deeper than 10 feet.

After the first two feet, the cost-effectiveness dredging to light-limiting depths declines dramatically. As shown in the Table 2-5 below, each additional 2-foot increment of dredging depth is only about half as effective at establishing light-limiting depths as the one before it.

Table 2-5: Dredging Depth Analysis

Dredging Depth	Total Lake Area > 10 ft. (acres)	New Area > 10 ft. (acres)	New Area > 10 ft. (% of lake)
0 feet	56.6	0	0
2 feet	177.0	120.4	34%
4 feet	237.2	60.2	17%
6 feet	269.1	31.9	9%

Another way to control macrophyte growth by dredging is to create a less suitable substrate for plant growth by removing soft, organic sediments and dredging down to an inorganic layer (e.g. sand, gravel). Based on the sediment depths measured by BSC, including both organic muck and peat layers, this approach is not recommended. The volume of sediment removal required to reach an inorganic layer over 50% of the lake area would be much greater than the volume of removal required to achieve light-limiting depths over 50% of the lake.

It is important to note that can macrophytes play a significant role in uptake of nutrients from the water column during the growing season. Nutrients that might otherwise be available for consumption by algae are instead taken out of the water column and stored in plant biomass. For this reason, dredging or any other technique that substantially reduces the macrophyte community within a lake can lead to an increase in algal productivity.

Algae Control

Dredging can also be used to remove nutrient-rich sediments that can lead to algal blooms. In deep lakes, thermal stratification in the summer can lead to anoxia (oxygen depletion) in the hypolimnion (deep water) portion of the lake. As a result of the anoxic conditions, phosphorus from nutrient-rich organic sediments can be re-released into the water column, fueling the growth of algae. In some lakes, this internal nutrient re-cycling can be a significant portion of the lake's total nutrient load. However, Lake Shirley is a relatively shallow reservoir that does not experience significant summer thermal stratification. As estimated by the 1988 D/F study, only a very small (10 kg/yr) portion of Lake Shirley's annual nutrient load is due to nutrient release from sediments. Therefore, design of a dredging program for Lake Shirley should not focus on control of seasonal sediment nutrient recycling.

Particularly in shallow lakes with highly flocculent organic sediments, such as Lake Shirley, the temporary resuspension of sediments due to disturbances such as motor boats and strong winds can also contribute to algal blooms and turbidity. When resuspended, nutrients attached to particulate matter may be released to the water column, fueling the growth of algae. The resuspended sediments also decrease water clarity, impairing the aesthetic qualities of the lake. As previously discussed in Section 1.2 (Water Quality Sampling Results), water quality testing in the summer of 1999 indicates that Lake Shirley has suffered from a dramatic decrease in water clarity and increased algae growth in recent years. This information is supported by anecdotal information from lake residents and the members of the Lake Shirley Improvement Corporation.

Although it was beyond the scope of this study to quantify the water quality impairment caused at Lake Shirley by sediment resuspension, the 1999 sediment sampling results and a review of Lake Shirley's bathymetric contours indicate that much of the lake is susceptible to temporary impacts of this type. Each of BSC's four sediment sampling sites (Figure 18) exhibited a top layer with several feet of extremely flocculent organic sediments. More than 25 percent of the lake area has a depth of 5 feet or less, shallow enough for a 10-horsepower boat to cause sediment resuspension (Yousef, 1974). Almost the entire lake is less than 15 feet deep, shallow enough for a 50-horsepower boat to cause sediment resuspension. Dredging could help improve water clarity and nuisance algae growth at Lake Shirley by removing the top-layer sediments most prone to temporary resuspension.

Dredging Volume

Based on the above discussion of dredging for the objectives of plant and algae control, a target removal of *no less than* two feet of sediment over 70% of the lake area (248 acres) is recommended, for a *minimum* total removal of approximately 807,000 cubic yards. This recommended sediment volume is roughly double the volume estimated by the 1988 M&E report. For the reasons given above, the one foot of sediment removal recommended by M&E would neither create a significant area with light–limiting depths, nor would it adequately remove the flocculent top-layer sediments that are prone to temporary resuspension. Since the cost of dredging is directly related to the volume of material dredged, it would be most cost-effective to focus on dredging the first two feet of sediment. Even in shallow areas where dredging two feet will not create light-limiting conditions or remove the entire organic muck layer, some macrophyte control would be achieved due to the removal of plant biomass, roots, seed stock, and sediment nutrient base. Dredging to greater depths would provide a greater area of plant control and greater longevity of control, but these advantages must be weighed against project costs and anticipated funding constraints.

Dredging Method

Hydraulic dredging is the method most commonly used for the removal of large quantities of lake sediments, such as are present at Lake Shirley. Hydraulic dredging involves the use of floating equipment, combining the use of a submerged cutter head to loosen and agitate sediments and suction to pump sediments out of the lake in a wet slurry form. The slurry, which is normally only 10% to 20% percent solids (80% to 90% water), must be pumped to a dewatering area, allowing the solids to settle and dry out for eventual disposal and the water to drain back towards the lake. The cutter heads on most hydraulic dredges have been designed specifically to loosen sand, silt or clay, and are less efficient at removing the type of highly flocculent sediments found in Lake Shirley. As a result, hydraulic dredging would probably yield a slurry with a higher than average water content, requiring a relatively large area for containment/dewatering.

Siting a dewatering area of sufficient size poses a major challenge at Lake Shirley, since homes surround much of the lakeshore. There are several active and inactive gravel pits in the vicinity of the lake that could potentially be used as dewatering areas. Other possibilities include agricultural land and other private lands which would require easements or outright purchase to be used for dewatering. A large commercial gravel operation, the Keating site, is located in sub-watershed E approximately 2100 feet south of the south end of the lake. Another pit located in sub-watershed B is just west of the junction of Reservoir Road and Flat Hill Road, about 1700 feet from the north end of the lake, and a third area is in sub-watershed B, approximately 1600 feet east of the northeast corner of the lake. However, none of these sites is immediately adjacent to the lake, which increases both the cost and difficulty of transporting the slurry and disposing of the water.

The 1997 Draft Generic Environmental Impact Report (GEIR) for Eutrophication and Aquatic Plant Management in Massachusetts reports highly variable costs for hydraulic dredging in the northeastern United States, ranging from $4 to $8 per cubic yard. Dredge material transportation, processing, and disposal costs are likely to range from $2 to $4 per cubic yard. At this price range, the hydraulic dredging 807,000 cubic yards would cost between 4.8 and 9.7 million dollars, with the higher end of this estimate being more realistic. However, this price could be substantially higher if substantial difficulties are encountered in siting sediment dewatering and disposal areas.

Disposal of such a large volume of sediment would be one of the biggest constraints to dredging. Very few landfills anywhere in the state could accept this volume, and disposal costs would be very high, even if a suitable site could be found. Determining the ultimate disposal of the sediment and obtaining the necessary permits and approvals will be a major part of the cost of any proposed dredging project. As described in Section 2.2, sediment testing indicates that the sediment could be placed in lined landfills and is likely to be clean enough for beneficial upland re-use. Additional testing to confirm TPH fractions will be required before any beneficial re-use us the sediments can be proposed. If these tests confirm that the sediment is appropriate for upland re-use, some reduction in total project cost could be realized if the sediment can be processed for use as topsoil dressing, potting soil, etc. However, substantial project cost reductions from dredge material re-use are almost never realized from large dredging projects.

An alternative method of sediment removal is to draw down the lake level and excavate the sediments with bulldozers and other conventional excavation equipment. The outlet structure at

Lake Shirley will allow a drawdown of at least nine feet, which would expose approximately 80% of the lake sediments.

Conventional excavation, or dry dredging, is most feasible for small reservoirs, with less than 30,000 cubic yards to be removed (Cooke *et al.*, 1993). This is only a very small fraction of the total soft sediment in Lake Shirley, and less than 4% of the 807,000 cubic yards that would be removed by dredging the first two feet over 70% of the lake. A tremendous amount of truck traffic, amounting to over 60,000 trips (based on 12 cubic yards per truck), would be generated by removal of the sediment. The basin would have to be allowed to dewater and compact before excavation equipment and trucks could operate safely on the sediments.

The total time required to dredge Lake Shirley by conventional means would be determined by the type and quantity of equipment used, and the total amount of material removed. For example, a combination of backhoes, front end loaders or bulldozers, along with enough trucks to keep the excavation equipment working continually (four or five 12 CY dump trucks), could maintain a production rate of approximately 1,050 cubic yards per day. At this rate, it would take 768 days to dredge 807,000 cubic yards. If dredging operations were conducted for 128 days each year during the winter months, allowing the lake to refill for summer recreation, the project would take six years to complete. It should be noted that these assumptions are *optimistic*, and that a variety of logistical considerations could easily extend the project duration by a several years. The problem of sediment disposal would be the same as hydraulic dredging, in that very few landfills could even accept this sediment, and would only do so at a very high cost.

Because dry dredging requires a draining most of the lake, the potential for impacts to private water supplies is a major concern. Many of the homes around Lake Shirley rely on fairly shallow private wells which may be impacted by a significant and extended drawdown required to conduct dredging. Before any dry dredging could take place, a detailed assessment of water supply impacts would have to be conducted as part of the permitting process (see Section 2.5, Permitting). If the water supply for a substantial number of homes will be impacted, the costs of providing an alternative water supply for the project duration could be prohibitive.

<u>Dredging Method Assessment Summary</u>

The main problems presented by dredging are cost, transportation, dewatering and disposal of very large amounts of sediment. Space in landfills is very limited, and finding a landfill that could accept this large amount of sediment could be difficult. More thorough analysis for TPH fractions will be required for consideration of beneficial upland re-use of sediments, consultation with state solid waste officials would be required, and the sediments would have to be stored, dewatered, and transported.

Overall, the financial and logistical constraints to dredging Lake Shirley appear very high: The *minimum* recommended dredge volume of 807,000 cubic yards is likely to result in a project cost of $7- 9 million dollars and poses a major sediment disposal problem. Private water supply issues associated with water level drawdown make are likely to make conventional dry dredging infeasible. The substantial space demands of sediment dewatering for a hydraulic dredging project are also a major constraint.

2.4 Dredging Permitting Assessment

Dredging is a complicated process with the potential for significant environmental impacts. As such, a dredging project at Lake Shirley would require an extensive permitting process involving local, state, and federal permits and approvals. A summary of the required permits is given below.

Local Permits

Notice of Intent:

A Notice of Intent (NOI) must be filed with the Lunenberg Conservation Commission for any dredging project in Lake Shirley, in compliance with the Massachusetts Wetlands Protection Act (WPA) regulations, 310 CMR 10.00. All of Lake Shirley below the mean annual low water level is classified by these regulations as Land Under a Water Body. According to the WPA regulations, any work in this area must not impair (1) groundwater and surface water quality, (2) escape cover and food for fisheries, (3) the capacity for wildlife habitat and breeding, and (4) the water carrying capacity within a channel. The WPA also regulates any proposed work within a 100-foot buffer zone to designated Wetland Resource Areas and within 200-feet of perennial streams. Aspects of a dredging project that have the potential to impact these regulated buffer zones include equipment staging areas and sediment dewatering operations.

After a NOI has been submitted, the Conservation Commission holds a public hearing on the proposed project, and has jurisdiction to either approve or deny the project. If the project is approved, the Conservation Commission may impose conditions designed to protect the above-mentioned interests of the WPA. Examples of such conditions include seasonal restrictions on the work, limitation of the type of equipment used, or erosion and sedimentation controls.

A NOI filing for a dredging project will involve analysis of sediment and water quality, fish and wildlife habitat impact assessment, and engineering design related to dredging and dewatering operations. If a lake level drawdown is proposed as part of a dredging plan, the Town Board of Health also requires an assessment of potential impacts to public and private water supply. Because the Lake Shirley dam/outlet control was recently rehabilitated, further hydraulic analysis related to the function of the dam during drawdown should not be required. Since many homes around Lake Shirley have shallow wells that may be impacted by a significant and protracted drawdown, this analysis will have to be carefully done and will represent an additional expense. Depending on the overall extent of the proposed dredging project, and whether a hearing closes promptly or is continued, a NOI filing could cost as much as $10,000 to $15,000.

State Permits

Superseding Order of Conditions:

If the applicant or an interested party (e.g., a direct abutter) objects to the decision of the Conservation Commission, either in approving or denying the project, or to conditions imposed, they may, within ten days of the issuance of the Order of Conditions, request the Department of Environmental Protection (DEP) to issue a Superseding Order of Conditions. The DEP has 70 days to issue a superseding order, unless they have requested additional plans or information, in which case they must issue a superseding order within 40 days of receipt of such information.

MEPA Review:

Under the regulations of the Massachusetts Environmental Policy Act (MEPA), an Environmental Notification Form (ENF) must be submitted to the Secretary of Environmental Affairs for any project proposing to dredge over 10,000 cubic yards of material. If the proposed dredging alters ten or more acres of lake bottom, an Environmental Impact Report (EIR) will also be required. Otherwise, the Secretary will review the ENF and determine whether an EIR is required.

The first page of the ENF is published in the *Environmental Monitor*, which starts an ENF review period of 30 days and a concurrent public comment period of 20 days. By the end of the ENF review period, the Secretary will determine whether an EIR is required and the scope of the EIR. The EIR will require extensive description of the project, analysis of alternatives, and assessment of impacts. Upon filing of the EIR another public comment and review period begins, and after 37 days, the Secretary will issue a certificate stating whether or not the EIR adequately and properly complies with MEPA and the MEPA regulations, 310 CMR 11.00.

The MEPA process would be the most expensive permitting effort required for a dredging project at Lake Shirley. Determining the ultimate disposal of the dredged material will be the most expensive part of the MEPA process. Costs for preparation of an ENF and EIR may range anywhere from $50,000 to $250,000, depending on factors such as the volume of dredged material, the quality of the material, and the availability of disposal sites.

Water Quality Certification:

Under Section 401 of the federal Clean Water Act, the DEP is required to certify that activities for which federal permits are needed will not violate the Massachusetts Water Quality Standards. If a U.S. Army Corps of Engineers permit is required, a 401 Water Quality Certification for Dredging Activities must be obtained for this project. The application requires a description of the project, including its length, width, depth, and volume, as well as a grain size and chemical analysis of the material to be dredged, and a description of the disposal site for the dredged material.

For projects that propose dredging more than 5,000 cubic yards, which would almost certainly include any feasible plan for Lake Shirley, a major project certification would be required. The fee for this application is $250, and the time line for DEP's review of the application includes a 30-day review for administrative completeness, followed by a 120 day technical review period. If DEP finds any deficiencies in the application, the applicant has 180 days to remedy those deficiencies, after which DEP has up to 120 days to complete a second technical review before issuing its certification. The chemical analysis required as part of this application will be one of the most important factors in determining disposal options for the dredged material.

If no Water Quality Certification is required because no federal permit is required, essentially the same information would have to be obtained as part of the MEPA process described above.

Division of Fisheries and Wildlife Notification:

If a lake level drawdown is proposed in conjunction with dry dredging, the Division of Fisheries and Wildlife must be notified at least ten days prior to drawdown.

Federal Permits

U.S. Army Corps of Engineers Permit:

An Army Corps of Engineers Permit is not necessary for a project involving only dredging in water bodies not defined as "navigable waters". However, under the Section 404 program, any discharge or fill into the lake would be regulated by the Corps. This would include water flowing back into the lake from dewatering activities, and any structures such as cofferdams placed into the lake during dredging activities. Hydraulic dredging will therefore probably require a Corps of

Engineers permit for the dewatering discharge, whereas dry dredging may not need a Corps permit. Before any work commences, confirmation should be sought in writing from the U.S. Army Corps of Engineers - New England District as to whether the proposed work requires a Corps permit. The Corps will also decide whether the work can be covered under a Programmatic General Permit, in which a separate application is not required, or whether the activity requires an individual permit.

Preparation of a Corps of Engineers permit requires the preparation of several drawings of the activity in a prescribed format, and a detailed description of the proposed activity.

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APPENDIX 1:

CLIMATE DATA

Description of Data

The climate data contained here is obtained from hourly observations used in operational forecasting. It is not official because of potential gaps in the data due to problems with communications etc. and because of potential errors which are not later corrected. The acquisition of this information is totally automated.

But inspite of this in most cases it is resonably accurate and many daily climate observations here are not available elsewhere on the internet.

The data begins with the end of May 1997. Each day of the month has an entry on one line. Data for a day for most of the parameters is for the period midnight to midnight EST (1 AM to 1 AM EDT). But total precipitation uses the period 1 AM to 1 AM EST (2 AM to 2 AM EDT). Before about June 23 1997 precipitation was from 8 PM to 8 PM EST. Data between September 11, 1997 and September 17 1997 is incomplete due to problems with the computer that acquires the data, it mainly affects maximum temperatures and data that occurred during the daylight hours.

The highest temperature of the day is listed under MxT. The lowest temperature of the day is listed under MnT. A * to the right of a value indicates it is an extreme for the month. AvT is the average daily temperature (the sum of MxT and MnT divided by 2.) This is followed by either HrlyT or HDDay. HrlyT is the average of the hourly temperatures for for each hour of the day. In most cases it is about the same as AvT. HDDay is the heating degree days. This is obtained by subtracting AvT from 65. Negative values are set to zero. AvDP is the average of the dew point for each hour of the day. 1HrP is the maximum precipitation that fell in one hour during the day. If 0.00 is shown it indicates a Trace. Tpcpn is the total precipitation for the day. T indicates a trace. 0.00 indicates either 0 precipitation fell or that the total for the day is missing.

WxType indicates the type of weather, if any, that occurred. The following abbreviations are used:

```
R Rain
T Thunderstorm
F Fog
L Drizzle
W Showers
H Haze
K Smoke
Z Freezing
B Blowing
S Snow
I Ice
A Hail
```

PDir is the prevailing wind direction in degrees (360 is north, 090 is east, 180 is south, 270 is west) averaged over 36 points of the compass. AvSp is the average wind speed in miles an hour. MxS is the maximum wind speed gust or peak wind in miles an hour. Dir is the direction that occurred with the peak gust. SkyC is the total sky cover is tenths. 10.0 indicates total cloud cover through the entire day. 0.0 indicates nearly clear. High thin clouds may not be included in the total sky cover for some locations. MxR is the maximum relative humidity for the day. MnR is the minimum relative humidity for the day.

Near the bottom if each monthly file is a line that starts with "mo". This contains averages or totals of selected daily values through the last day of the month that is available. For instance under the MxT column it is the average maximum temperature from the first of the month (if it is available) through the last day of the month (or the previous day if it is a current month.

A final line may follow the "mo" line and will start with "dp". It is not available for all locations and will not be shown when not available. The "dp" line contains the deparature of data on the "mo" line from normal. It is either the deparature from normal for the entire month, or in cases where the month is not yet complete it is the deparature from normal for the month to date.

Daily Climate Data

FIT 06 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	88	57	73		55.8		T		200	5.8	220	25	0.7	80	30
2	86	67	77		62.6	0.00	T	H	190	5.9	210	12	3.0	84	48
3	84	66	75		59.7		0.00		270	11.2	300	24	2.9	73	49
4	76	52	64	1	45.0	0.00	T	S	330	9.1	350	26	2.0	80	29
5	78	49	64	1	46.0		0.00		190	6.2	190	21	1.1	80	31
6	81	55	68		49.8		0.00		190	7.2	190	21	0.0	66	36
7	97*	67	82		65.4		0.00	H	290	9.1	270	23	0.0	76	39
8	89	73	81		60.8		0.00	H	290	10.3	290	36	1.4	69	33
9	73	55	64	1	54.1	0.01	0.01	RF	050	5.3	030	16	8.3	96	59
10	72	45	59	6	45.4		0.00		100	5.0		18	3.6	93	31
11	79	45	62	3	46.2		0.00		120	2.9	140	8	2.8	100	23
12	83	48	66		54.6		0.00		120	4.4		147*	0.0	97	27
13	83	61	72		64.8		0.00	FH	140	5.5	150	21	5.8	97	58
14	80	68	74		65.9	0.19	0.26	RFH	160	9.0	190	29	7.0	97	64
15	79	54	67		52.3	0.00	T		280	9.0	300	24	3.1	84	36
16	71	44*	58	7	44.3		0.00		120	5.0	350	8	1.1	89	40
17	67	53	60	5	49.7	0.03	0.07	R	330	2.9		7	4.8	93	45
18	70	50	60	5	52.6	0.02	0.01	R	360	4.0	350	10	6.4	96	49
19	78	48	63	2	49.7	0.01	0.00		330	3.9	350	7	2.6	96	36
20	80	55	68		50.2		0.00		190	4.7	200	16	1.8	83	36
21	79	54	67		49.5		0.00		170	4.7	150	12	1.6	77	32
22	87	54	71		53.9		0.00		340	4.7	350	10	1.7	86	31
23	88	58	73		59.5	0.10	0.10	R	340	3.7	200	13	0.3	90	36
24	90	63	77		55.9		0.00		230	5.7		17	0.5	90	30
25	82	57	70		56.8	0.00	T	R	230	6.8	230	23	1.7	83	44
26	92	66	79		58.1		0.00		280	8.3		18	0.0	87	27
27	94	62	78		58.6		0.00		170	6.8	150	20	0.0	79	26
28	93	73	83		70.4	0.21	0.46	RFH	190	7.7	210	25	5.8	100	47
29	89	70	80		72.0	0.44	0.49	RFH	190	6.4	270	32	5.9	100	59
30	81	63	72		57.9	0.00	T		140	6.9	280	20	0.8	87	45
mo	82.3	57.7	70.0	31	55.6		1.40			6.3			2.6		

FIT 07 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	74	64	69		65.6	0.04	0.11	RF	070	3.9	180	14	8.4	100	70
2	82	66	74		69.5	0.16	0.24	RWF	200	9.9	190	30	6.3	97	67
3	88	62	75		62.7	0.01	0.01	F	250	5.6	240	18	0.2	100	39
4	88	71	80		70.4	0.21	0.28	RF	280	6.7	230	31	3.2	97	55
5	95	76	86		73.3		0.00	H	270	7.7		35	0.0	88	48
6	96*	73	85		71.7	0.11	0.14	R	270	7.6	290	52*	1.0	93	46
7	83	63	73		56.6	0.00	0.00		280	10.9	280	30	0.0	82	38
8	77	59	68		51.9	0.01	0.01	R	270	7.5	280	31	0.8	84	37
9	74	60	67		55.1	0.00	0.03	R	230	6.3	210	20	3.9	87	55
10	86	59	73		59.6	0.03	T	RF	240	10.9	280	32	2.0	93	41
11	77	53	65		49.0		0.00		310	6.0	270	21	0.5	86	31
12	81	50*	66		50.4		0.00		160	3.8	160	9	0.0	93	31
13	74	54	64	1	54.1	0.01	0.01	R	070	3.5	150	12	4.3	93	44
14	82	52	67		55.8	0.01	0.01		210	3.3	280	8	2.4	93	38
15	88	60	74		57.1		0.00		270	3.9	250	12	0.0	93	29
16	93	67	80		63.8		0.00	H	320	5.6	260	13	0.0	82	39
17	95	71	83		67.0		0.00	FH	290	8.8	270	24	0.0	87	39
18	95	73	84		66.8	0.00	T	H	270	6.3	280	21	0.1	82	34
19	91	65	78		65.5	0.14	0.31	RFH	300	4.8	340	29	4.5	93	43
20	82	56	69		53.8	0.01	0.01		300	6.7	320	18	1.2	93	32
21	84	52	68		51.7		0.00		330	4.6	240	10	0.0	86	28
22	87	68	78		64.0	0.00	T		200	7.2	240	20	2.8	84	46
23	93	68	81		65.4	0.00	T	RFH	310	4.6	280	21	2.5	90	32
24	93	66	80		67.8	0.38	0.47	RFH	150	3.9	240	21	1.1	100	44
25	87	66	77		68.6	0.01	0.01	FH	040	3.8	030	16	4.6	100	61
26	79	65	72		66.8	0.08	0.17	RFH	110	2.7	140	10	3.7	97	67
27	88	65	77		64.5	0.01	0.00	F	310	5.8	280	13	3.7	97	43
28	89	67	78		56.9		0.00		300	7.2	270	21	0.0	76	31
29	86	63	75		61.6	0.00	T		050	4.2	300	13	0.9	90	44
30	90	67	79		67.7	0.04	0.06	RFH	140	2.4	140	10	1.7	100	45
31	91	67	79		69.5		0.00	FH	170	5.0	160	13	2.8	100	49
mo	86.1	63.5	74.8	1	62.1		1.87			5.9			2.0		

Daily Climate Data

FIT 08 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	94*	68	81		66.8		0.00	H	280	8.4	270	20	3.4	87	38
2	85	59	72		55.0		0.00		350	5.5	290	20	1.3	87	34
3	83	56	70		52.0		0.00		310	3.8	250	16	1.7	86	32
4	87	55	71		55.2		0.00		190	5.6	260	16	1.9	93	32
5	85	63	74		62.4	0.14	0.21	RF	150	3.9	140	23	3.8	100	48
6	84	56	70		56.2	0.01	0.01	R	240	5.8	330	23	3.3	96	37
7	81	57	69		52.6		0.00		300	7.0	320	22	0.1	87	34
8	79	61	70		63.9	0.14	0.18	RFH	310	5.6	270	21	6.1	97	71
9	74	51	63	2	46.7		0.00		310	8.5	310	33*	1.4	93	29
10	75	49*	62	3	44.8	0.00	T	R	330	4.5		16	3.3	83	33
11	68	60	64	1	60.3	0.06	0.10	RF	130	1.6	110	6	9.9	100	60
12	88	62	75		62.0	0.01	0.01	F	300	3.5	130	8	3.8	100	37
13	90	61	76		66.8	0.01	0.01	RH	170	8.1	180	24	3.5	97	50
14	81	69	75		70.2	0.10	0.13	R	190	7.2	200	22	6.9	100	69
15	69	60	65		62.1	0.04	0.17	RF	340	5.4	040	10	9.0	100	84
16	82	54	68		58.1	0.01	0.00		320	4.1	300	17	0.6	100	39
17	90	66	78		66.0		0.00	FH	200	6.8	210	21	1.1	93	42
18	83	62	73		62.1	0.00	T	FH	310	7.0	290	20	1.8	90	46
19	80	55	68		52.1		0.00		340	3.9	120	10	0.8	96	32
20	77	54	66		52.1	0.01	0.01	R	140	5.2	160	17	1.9	93	37
21	61	56	59	6	56.4	0.20	0.67	RF	360	6.9	340	14	9.9	100	81
22	67	56	62	3	56.8	0.02	0.05	RF	330	4.3	350	8	9.0	100	70
23	83	57	70		57.1		0.00		320	4.1	330	8	3.2	93	38
24	86	59	73		57.9		0.00		340	3.3	180	8	0.0	93	32
25	86	58	72		58.6		0.00	H	200	3.4	180	12	0.4	96	38
26	79	60	70		60.6	0.00	T	RF	110	2.9	120	9	3.7	97	43
27	73	65	69		68.3	0.33	0.77	RF	070	2.7	350	8	9.1	100	87
28	86	67	77		66.0	0.01	0.00	FH	270	6.2	270	21	2.8	100	49
29	82	56	69		54.6		0.00		270	9.8	350	23	2.4	71	37
30	73	51	62	3	47.1		0.00		360	8.7	340	24	0.5	80	41
31	75	52	64	1	45.3	0.00	T	R	330	5.4	050	18	0.0	90	29
mo	80.2	58.5	69.4	19	57.9		2.32			5.5			3.4		

FIT 09 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	84	49	67		49.8		0.00		330	2.6	330	6	0.0	93	29
2	90	51	71		54.6		0.00		320	2.5	320	6	0.0	93	25
3	91*	60	76		57.4		0.00		330	3.1	290	7	0.0	90	29
4	88	62	75		58.2		0.00		130	2.4	120	10	0.4	84	33
5	83	65	74		64.9		0.00		100	4.1	080	10	8.0	93	53
6	81	69	75		70.6	0.07	0.26	RF	130	5.1	110	10	9.1	100	79
7	85	70	78		69.0	0.01	0.01	RF	150	6.8	140	15	7.6	100	55
8	80	70	75		69.2	0.04	0.09	RFH	160	5.8	180	13	4.8	97	69
9	84	70	77		67.6		0.00	FH	170	6.6	180	22	5.2	93	55
10	74	65	70		67.8	1.12	3.13	RF	140	4.4	180	16	8.8	100	82
11	77	54	66		56.2	0.01	0.01	F	290	5.1	270	22	0.7	100	39
12	77	50	64	1	51.8	0.01	0.01		300	3.3	240	9	0.0	96	40
13	78	49	64	1	51.9	0.01	0.01		140	4.3	120	13	0.0	96	39
14	72	55	64	1	58.8	0.01	0.01	R	150	3.5	170	13	7.5	96	70
15	72	61	67		63.4	0.06	0.32	RF	120	1.5	120	7	7.1	100	76
16	69	57	63	2	60.8	0.63	3.93	RF	030	7.6	090	35	10.0	100	87
17	68	53	61	4	50.3	0.08	0.16	RF	300	16.4	290	40*	7.5	100	60
18	71	46	59	6	44.0		0.00		300	7.9	320	30	0.0	93	34
19	73	41	57	8	46.1	0.01	0.01		340	2.8	060	7	0.0	96	39
20	73	44	59	6	50.6	0.01	0.00		180	5.0	140	13	0.8	100	48
21	64	54	59	6	59.7	0.12	0.46	RF	330	2.4	130	6	8.0	100	93
22	61	50	56	9	53.5	0.01	0.03	RF	300	7.9	290	23	9.9	100	80
23	71	47	59	6	46.1		0.00		300	8.7	280	23	1.0	83	44
24	77	48	63	2	52.6		0.00		200	5.9	210	24	0.0	100	40
25	73	47	60	5	52.6	0.02	0.03	RFH	290	5.4	270	21	2.9	96	39
26	67	41*	54	11	45.3		0.00	H	170	1.3		7	0.0	96	45
27	71	43	57	8	52.0	0.01	0.01	F	190	2.3	190	9	1.1	100	61
28	75	53	64	1	59.4		0.01	F	180	2.3	160	9	5.4	100	66
29	71	60	66		60.4	0.01	T	FH	160	6.8	180	18	9.5	100	71
30	67	45	56	9	53.5	0.22	0.57	RF	130	10.7	150	32	5.0	100	54
mo	75.6	54.3	64.9	86	56.6		9.06			5.2			4.0		

Daily Climate Data

FIT 06 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	88	57	73		55.8		T		200	5.8	220	25	0.7	80	30
2	86	67	77		62.6	0.00	T	H	190	5.9	210	12	3.0	84	48
3	84	66	75		59.7		0.00		270	11.2	300	24	2.9	73	49
4	76	52	64	1	45.0	0.00	T	S	330	9.1	350	26	2.0	80	29
5	78	49	64	1	46.0		0.00		190	6.2	190	21	1.1	80	31
6	81	55	68		49.8		0.00		190	7.2	190	21	0.0	66	36
7	97•	67	82		65.4		0.00	H	290	9.1	270	23	0.0	76	39
8	89	73	81		60.8		0.00	H	290	10.3	290	36	1.4	69	33
9	73	55	64	1	54.1	0.01	0.01	RF	050	5.3	030	16	8.3	96	59
10	72	45	59	6	45.4		0.00		100	5.0		18	3.6	93	32
11	79	45	62	3	46.2		0.00		120	2.9	140	8	2.8	100	23
12	83	48	66		54.6		0.00		120	4.4		147•	0.0	93	27
13	83	61	72		64.8		0.00	FH	140	5.5	150	21	5.8	97	58
14	80	68	74		65.9	0.19	0.26	RFH	160	9.0	190	29	7.0	97	64
15	79	54	67		52.3	0.00	T		280	9.0	300	24	3.1	84	36
16	71	44•	58	7	44.3		0.00		120	5.0	350	8	1.1	89	40
17	67	53	60	5	49.7	0.03	0.07	R	330	2.9		7	4.8	93	45
18	70	50	60	5	52.6	0.02	0.01	R	360	4.0	350	10	6.4	96	49
19	78	48	63	2	49.7	0.01	0.00		330	3.9	350	7	2.6	96	36
20	80	55	68		50.2		0.00		190	4.7	200	16	1.8	83	36
21	79	54	67		49.5		0.00		170	4.7	150	12	1.6	77	32
22	87	54	71		53.9		0.00		340	4.7	350	10	1.7	86	31
23	88	58	73		59.5	0.10	0.10	R	340	3.7	200	13	0.3	90	36
24	90	63	77		55.9		0.00		230	5.7		17	0.5	90	30
25	82	57	70		56.8	0.00	T	R	230	6.8	230	23	1.7	83	44
26	92	66	79		58.1		0.00		280	8.3		18	0.0	87	27
27	94	62	78		58.6		0.00		170	6.8	150	20	0.0	79	26
28	93	73	83		70.4	0.21	0.46	RFH	190	7.7	210	25	5.8	100	47
29	89	70	80		72.0	0.44	0.49	RFH	190	6.4	270	32	5.9	100	59
30	81	63	72		57.9	0.00	T		140	6.9	280	20	0.8	87	45
mo	82.3	57.7	70.0	31	55.6		1.40			6.3			2.6		

FIT 07 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	74	64	69		65.6	0.04	0.11	RF	070	3.9	180	14	8.4	100	70
2	82	66	74		69.5	0.16	0.24	RWF	200	9.9	190	30	6.3	97	67
3	88	62\	75		62.7	0.01	0.01	F	250	5.6	240	18	0.2	100	39
4	88	71	80		70.4	0.21	0.28	RF	280	6.7	230	31	3.2	97	55
5	95	76	86		73.3		0.00	H	270	7.7		35	0.0	88	48
6	96•	73	85		71.7	0.11	0.14	R	270	7.6	290	52•	1.0	93	46
7	83	63	73		56.6	0.00	0.00		280	10.9	280	30	0.0	82	38
8	77	59	68		51.9	0.01	0.01	R	270	7.5	280	31	0.8	84	37
9	74	60	67		55.1	0.00	0.03	R	230	6.3	210	20	3.9	87	55
10	86	59	73		59.6	0.03	T	RF	240	10.9	280	32	2.0	93	41
11	77	53	65		49.0		0.00		310	6.0	270	21	0.5	86	31
12	81	50•	66		50.4		0.00		160	3.8	160	9	0.0	93	31
13	74	54	64	1	54.1	0.01	0.01	R	070	3.9	150	12	4.3	93	44
14	82	52	67		55.8	0.01	0.01		210	3.3	280	8	2.4	93	38
15	88	60	74		57.1		0.00		270	3.9	250	12	0.0	93	29
16	93	67	80		63.8		0.00	H	320	5.6	260	13	0.0	82	39
17	95	71	83		67.0		0.00	FH	290	8.8	270	24	0.0	87	39
18	95	73	84		66.8	0.00	T	H	270	6.3	280	21	0.1	82	34
19	91	65	78		65.5	0.14	0.31	RFH	300	4.8	340	29	4.5	93	43
20	82	56	69		53.8	0.01	0.01		300	6.7	320	18	1.2	93	32
21	84	52	68		51.7		0.00		330	4.6	240	10	0.0	86	28
22	87	68	78		64.0	0.00	T		200	7.2	240	20	2.8	84	46
23	93	68	81		65.4	0.00	T	RFH	310	4.6	280	21	2.5	90	32
24	93	66	80		67.8	0.38	0.47	RFH	150	3.9	240	21	1.1	100	44
25	87	66	77		68.6	0.01	0.01	FH	040	3.8	030	16	4.6	100	61
26	79	65	72		66.8	0.08	0.17	RFH	110	2.7	140	10	3.7	97	67
27	88	65	77		64.5	0.01	0.00	F	310	5.8	280	13	3.7	97	43
28	89	67	78		56.9		0.00		300	7.2	270	21	0.0	76	31
29	86	63	75		61.6	0.00	T		050	4.2	300	13	0.9	90	44
30	90	67	79		67.7	0.04	0.06	RFH	140	2.4	140	10	1.7	100	45
31	91	67	79		69.5		0.00	FH	170	5.0	160	13	2.8	100	49
mo	86.1	63.5	74.8	1	62.1		1.87			5.9			2.0		

Daily Climate Data

FIT 08 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	94•	68	81		66.8		0.00	H	280	8.4	270	20	3.4	87	38
2	85	59	72		55.0		0.00		350	5.5	290	20	1.3	87	34
3	83	56	70		52.0		0.00		310	3.8	250	16	1.7	86	32
4	87	55	71		55.2		0.00		190	5.6	260	16	1.9	93	32
5	85	63	74		62.4	0.14	0.21	RF	150	3.9	140	23	3.8	100	48
6	84	56	70		56.2	0.01	0.01	R	240	5.8	330	23	3.3	96	37
7	81	57	69		52.6		0.00		300	7.0	320	22	0.1	87	34
8	79	61	70		63.9	0.14	0.18	RFH	310	5.6	270	21	6.1	97	71
9	74	51	63	2	46.7		0.00		310	8.5	310	33•	1.4	93	29
10	75	49•	62	3	44.8	0.00	T	R	330	4.5		16	3.3	83	33
11	68	60	64	1	60.3	0.06	0.10	RF	130	1.6	110	6	9.9	100	60
12	88	62	75		62.0	0.01	0.01	F	300	3.5	130	8	3.8	100	37
13	90	61	76		66.8	0.01	0.01	RH	170	8.1	180	24	3.5	97	50
14	81	69	75		70.2	0.10	0.13	R	190	7.2	200	22	6.9	100	69
15	69	60	65		62.1	0.04	0.17	RF	340	5.4	040	10	9.0	100	84
16	82	54	68		58.1	0.01	0.00		320	4.1	300	17	0.6	100	39
17	90	66	78		66.0		0.00	FH	200	6.8	210	21	1.1	93	42
18	83	62	73		62.1	0.00	T	FH	310	7.0	290	20	1.8	90	46
19	80	55	68		52.1		0.00		340	3.9	120	10	0.8	96	32
20	77	54	66		52.1	0.01	0.01	R	140	5.2	160	27	2.9	93	37
21	61	56	59	6	56.4	0.20	0.67	RF	360	6.9	340	14	9.9	100	81
22	67	56	62	3	56.8	0.02	0.05	RF	330	4.3	350	8	9.0	100	70
23	83	57	70		57.1		0.00		320	4.1	330	8	3.2	93	38
24	86	59	73		57.9		0.00		340	3.3	180	8	0.0	93	32
25	86	58	72		58.6		0.00	H	200	3.4	180	12	0.4	96	38
26	79	60	70		60.6	0.00	T	RF	110	2.9	120	9	3.7	97	43
27	73	65	69		68.3	0.33	0.77	RF	070	2.7	350	8	9.1	100	87
28	86	67	77		66.0	0.01	0.00	FH	270	6.2	270	21	2.8	100	49
29	82	56	69		54.6		0.00		270	9.8	350	23	2.4	71	37
30	73	51	62	3	47.1		0.00		360	8.7	340	24	0.5	80	41
31	75	52	64	1	45.3	0.00	T	R	330	5.4	050	18	0.0	90	29
mo	80.2	58.5	69.4	19	57.9		2.32			5.5			3.4		

FIT 09 99

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR
1	84	49	67		49.8		0.00		330	2.6	330	6	0.0	93	29
2	90	52	71		54.6		0.00		320	2.5	320	6	0.0	93	25
3	91•	60	76		57.4		0.00		330	3.1	290	7	0.0	90	29
4	88	62	75		58.2		0.00		130	2.4	120	10	0.4	84	33
5	83	65	74		64.9		0.00		100	4.1	080	10	8.0	93	53
6	81	69	75		70.6	0.07	0.26	RF	130	5.1	110	10	9.1	100	79
7	85	70	78		69.0	0.01	0.01	RF	150	6.8	140	15	7.6	100	55
8	80	70	75		69.2	0.04	0.09	RFH	160	5.8	180	13	4.8	97	69
9	84	70	77		67.6		0.00	FH	170	6.6	180	22	5.2	93	55
10	74	65	70		67.8	1.12	3.13	RF	140	4.4	180	16	8.8	100	82
11	77	54	66		56.2	0.01	0.01	F	290	5.1	270	22	0.7	100	39
12	77	50	64	1	51.8	0.01	0.01		300	3.3	240	9	0.0	96	40
13	78	49	64	1	51.9	0.01	0.01		140	4.3	120	13	0.0	96	39
14	72	55	64	1	58.8	0.01	0.01	R	150	3.5	170	13	7.5	96	70
15	72	61	67		63.4	0.06	0.32	RF	120	1.5	120	7	7.1	100	76
16	69	57	63	2	60.8	0.63	3.93	RF	030	7.6	090	35	10.0	100	87
17	68	53	61	4	50.3	0.08	0.16	RF	300	16.4	290	40•	7.5	100	60
18	71	46	59	6	44.0		0.00		300	7.9	320	30	0.0	93	34
19	73	41	57	8	46.1	0.01	0.01		340	2.8	060	7	0.0	96	39
20	73	44	59	6	50.6	0.01	0.00		180	5.0	140	13	0.8	100	48
21	64	54	59	6	59.7	0.12	0.46	RF	330	2.4	130	6	8.0	100	93
22	61	50	56	9	53.5	0.01	0.03	RF	300	7.9	290	23	9.9	100	80
23	71	47	59	6	46.1		0.00		300	8.7	280	23	1.0	83	44
24	77	48	63	2	52.6		0.00		200	5.9	210	24	0.0	100	40
25	73	47	60	5	52.6	0.02	0.03	RFH	290	5.4	270	21	2.9	96	39
26	67	41•	54	11	45.3		0.00	H	170	1.3		7	0.0	96	45
27	71	43	57	8	52.0	0.01	0.01	F	190	2.3	190	9	1.1	100	61
28	75	53	64	1	59.4		0.01	F	180	2.3	160	9	5.4	100	66
29	71	60	66		60.4	0.01	T	FH	160	6.8	180	18	9.5	100	71
30	67	45	56	9	53.5	0.22	0.57	RF	130	10.7	150	32	5.0	100	54
mo	75.6	54.3	64.9	86	56.6		9.06			5.2			4.0		

DEPARTMENT OF ENVIRONMENTAL MANAGEMENT
DIVISION OF RESOURCE CONSERVATION
OFFICE OF WATER RESOURCES
WATER RESOURCES DATA COLLECTION & ANALYSIS PROGRAM

JUNE 1999
MASSACHUSETTS MONTHLY PRECIPITATION
COMPOSITE

REGION	NORMAL	ACTUAL	EXCESS/ DEFICIT	EXCESS OR DEFICIT SINCE LAST JAN.1,1999	OCT.1,1998	12 MONTHS
STATE	3.56	1.61	-1.94	-1.69	-4.20	-8.65
NORTHEAST	3.34	.60	-2.74	-2.64	-5.13	-8.83
SOUTHEAST	3.22	.33	-2.90	-.70	-3.80	-4.89
CENTRAL	3.81	1.02	-2.78	-4.04	-7.07	-11.69
CONNECTICUT RIVER	3.91	3.09	-.82	-.35	-3.81	-9.29
WESTERN	3.99	3.95	-.04	3.88	1.24	-4.52

June 1999 precipitation was substantially below normal throughout Massachusetts, with a deficit shown in every region of the state on the composite above. The central region of Massachusetts has experienced the greatest deficit during the current water year (beginning October 1, 1998). Western MA had near normal precipitation during June. In general, precipitation did not occur until late June and the first week of July. June 1999 streamflow and ground water levels were also low (within the lowest 25 percent of record for this month) throughout the state, according to US Geological Survey data. New record low discharges (streamflow) were recorded at 10 gaging stations with more than 40 years of record in central and eastern MA. The June 1999 Standard Precipitation Index (SPI) map at http://enso.unl.edu/ndmc/watch indicated near normal conditions in Massachusetts except for the southeast and Cape Cod, where extremely dry conditions were characterized.

DEPARTMENT OF ENVIRONMENTAL MANAGEMENT
DIVISION OF RESOURCE CONSERVATION
OFFICE OF WATER RESOURCES
WATER RESOURCES DATA COLLECTION & ANALYSIS PROGRAM

JULY 1999
MASSACHUSETTS MONTHLY PRECIPITATION
COMPOSITE

REGION	NORMAL	ACTUAL	EXCESS/ DEFICIT	EXCESS OR DEFICIT SINCE LAST JAN.1,1999	OCT.1,1998	12 MONTHS
STATE	3.64	2.53	-1.11	-2.80	-5.31	-8.16
NORTHEAST	3.48	3.30	-.18	-2.82	-5.32	-7.89
SOUTHEAST	3.10	3.85	.75	.04	-3.05	-3.18
CENTRAL	3.68	2.86	-.83	-4.87	-7.90	-11.55
CONNECTICUT RIVER	4.00	2.26	-1.74	-2.09	-5.55	-9.23
WESTERN	4.28	2.92	-1.36	2.52	-.12	-4.47

July precipitation was generally slightly below normal, with the greatest departure from normal in the Connecticut River valley. Precipitation generally occurred in localized thunderstorms. During July, moderate to severe drought conditions persisted in Massachusetts (with the exception of Berkshire County) as a result of the lack of precipitation in April and June. Ground water and streamflow levels were low, although streamflow recovered slightly with increased precipitation in July.

Precipitation since the beginning of the current water year (October 1998) is below normal in every region of the Commonwealth, with the greatest departure at 7.90 inches in Central Massachusetts. An active hurricane season during August and September 1999 is expected to mitigate drought conditions in Massachusetts.

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AUGUST 1999
MASSACHUSETTS MONTHLY PRECIPITATION
COMPOSITE

REGION	NORMAL	ACTUAL	EXCESS/ DEFICIT	EXCESS OR DEFICIT SINCE LAST JAN.1,1999	OCT.1,1998	12 MONTHS
STATE	3.98	3.15	-.83	-3.63	-6.14	-7.47
NORTHEAST	3.60	1.94	-1.66	-4.48	-6.97	-8.23
SOUTHEAST	4.03	3.02	-1.02	-.97	-4.06	-5.11
CENTRAL	3.92	3.19	-.73	-5.51	-8.63	-10.36
CONNECTICUT RIVER	3.94	3.26	-.69	-2.77	-6.23	-7.28
WESTERN	4.10	3.49	-.61	1.91	-.73	-2.32

Attached is the August 1999 rainfall composite for Massachusetts. The attachment is in the form of a text file that recipients should be able to open into word processing programs such as Word or WordPerfect.

The composite shows that August precipitation was 0.61 to 1.66 inches below normal across the Commonwealth, with the greatest deficiency in the northeast region (approximately 50 percent of normal). In other Massachusetts regions, precipitation was above 75 percent of normal.

Western Massachusetts' precipitation deficit is less than one inch for the current water year (October through September). The precipitation deficit in Central Massachusetts remains the greatest, at 8.63 inches below normal for the water year.

The Massachusetts Emergency Management Agency convened a meeting of state officials on August 31, 1999 to discuss the lack of precipitation experienced during the summer. The group concluded that the conditions did not warrant immediate action; concern was focused on the continuation of the precipitation deficit through the winter and into the spring of 2000. In the event of a continued deficit, water conservation efforts would have to be highly publicized and implemented early in the spring. A drought preparedness plan was also proposed to facilitate mitigation actions in the event of a future drought.

Streamflow and ground water levels responded favorably to August precipitation but remained lower than normal at the end of the month. Heavy rain on September 10 increased streamflow rates throughout the Commonwealth and above median levels at some locations. Additional precipitation expected this week associated with a front advancing from the west and from Hurricane Floyd may eliminate the precipitation deficit by September 17. Current forecasts from the National Weather Service are that Floyd's impacts may result in 4 to 6 inches of rain and flooding.

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SEPTEMBER 1999
MASSACHUSETTS MONTHLY PRECIPITATION
COMPOSITE

REGION	NORMAL	ACTUAL	EXCESS/ DEFICIT	EXCESS OR DEFICIT SINCE LAST JAN.1,1999	OCT.1,1998	12 MONTHS
STATE	3.72	8.47	4.75	1.12	-1.39	-1.39
NORTHEAST	3.62	9.19	5.56	1.09	-1.40	-1.40
SOUTHEAST	3.72	7.17	3.45	2.48	-.62	-.62
CENTRAL	3.94	9.95	6.01	.51	-2.61	-2.61
CONNECTICUT RIVER	*3.96*	*12.20*	*8.24*	*5.48*	*2.02*	*2.02*
WESTERN	4.03	9.02	4.98	6.89	4.25	4.25

Attached is the September 1999 rainfall composite for Massachusetts. The attachment is in the form of a text file that recipients should be able to open into word processing programs such as Word or WordPerfect.

As a result of heavy precipitation in September, the cumulative precipitation for the past 12 months has returned to nearly normal levels following a dry summer. Rainfall data indicate that September precipitation in Massachusetts was generally seven to ten inches above normal and double the normal amounts. More than 12 inches of rain were recorded at several locations in the Connecticut River valley and precipitation was approximately three times normal in this area.

September ground water levels were at or above normal throughout most of the Commonwealth, although ground water levels on Cape Cod remain within the lowest quartile of U.S. Geological Survey record. The USGS reported that September streamflow was above normal in all of Massachusetts, reversing a trend of low streamflow and water table levels during the summer of 1999.

APPENDIX 2:

LAKE SHIRLEY EXTERNAL PHOSPHORUS LOADING MODEL

External Total Phosphorus (TP) Loading Model:

Lex= ((0.5)*(house septics)) + ((0.13)*(forest ha)) + ((0.3)*(rural ha)) + ((14)*(urban ha^0.5))

Sub-watershed	Septic Loading (kg/yr)	Forest Loading (kg/yr)	Rural Loading (kg/yr)	Urban Loading (kg/yr)	Predicted Total Loading (kg/yr)	Calibrated Total Loading (kg/yr)
A	0.00	57.14	75.82	121.70	254.66	125.87
B	0.00	149.92	200.08	214.76	564.77	279.14
C	0.00	6.96	5.50	18.25	30.71	15.18
D	0.00	8.17	2.82	0.00	10.98	5.43
E	0.00	7.11	8.48	104.17	119.76	59.19
F (excluding septics)	-	17.73	13.09	86.19	117.01	57.83
F (septics only)	109.50	-	-	-	-	109.50
Total load (kg/yr)	0.00	247.03	305.79	545.08	1097.89	652.14
% of Total Watershed Loading	0.00	22.50	27.85	49.65	100.00	100.00

Model Input (fixed cells)

Sub-watershed	# of Septics	Forest (ha)	Rural (ha)	Urban (ha)
A	0	439.54	252.72	75.57
B	0	1153.24	666.94	235.33
C	0	53.52	18.35	1.70
D	0	62.84	9.39	0.00
E	0	54.70	28.27	55.36
F	219	136.37	43.63	37.91
Total	219	1900.20	1019.29	405.86

External Total Phosphorus (TP) Loading Model - Calibration Data

BSC Site ID (M&E Site ID)	Inflow (cfs)	% of Total Surface Water Inflow
Area A (L2)	3.86	27.34
Area B (L3)	8.3	58.78
Area C (LS6)	0.13	0.92
Area D (L4)	0.61	4.32
Area E (L1)	0.48	3.40
Area F (L0, LS3, LS5, Direct Runoff)	0.74	5.24
Total	14.12	100.00

BSC Site ID (M&E Site ID)	Averaged Dry and Wet TP concentration (mg/l)	Inflow (liters/year)	Average TP Loading (mg/year)	Average TP Loading (kg/year)	Notes:
Area A (L2)	0.0375	3446146857.600	129230507.160	129.231	
Area B (L3)	0.035	7410108528.000	259353798.480	259.354	
Area C (LS6)	0.17	116061940.800	19730529.936	19.731	No Flow Observed during sampling period - used M&E conc. data
Area D (L4)	0.035	544598337.600	19060941.816	19.061	No Dry Flow, only Wet Flow during sampling period
Area E (L1)	0.1	428536396.800	42853639.680	42.854	No Dry Flow, only Wet Flow during sampling period
Area F (L0, LS3, LS5, Direct Runoff) (Area F does not include septic TP loading)	0.109484 ((0.021*0.176)+(0.4*0.024)+(0.28*0.0176)+(0.117*0.78))	660660278.400	72331729.920	72.332	No Dry Flow, only Wet Flow during sampling period used M&E conc. Data to determine weighted average conc
Total		12606112339.200	542561146.992	542.561	

BSC Site ID (M&E Site ID)	TP Loading Using BSC 1999 TP Conc. Based on Field Data and M & E conc. Data (kg/year)	TP Loading Using DEP Loading Model (kg/year)	Amount DEP TP model over/under predicted Annual TP Load (%)
Area A (L2)	129.231	254.658	97.057
Area B (L3)	259.354	564.768	117.760
Area C (LS6)	19.731	30.708	55.637
Area D (L4)	19.061	10.984	-42.372
Area E (L1)	42.854	119.760	179.463
Area F (L0, LS3, LS5, Direct Runoff) (Area F does not include septic TP loading)	72.332	117.012	61.771
Total	542.561	1097.890	102.353
Ave. Predicted TP Conc. (mg/l)	0.043	0.087	

BSC Site ID (M&E Site ID)	Predicted TP Loading Using DEP TP Loading Model (kg/year)	Calibrated Model Predicted TP Loading Using Field Data (kg/year)
Area A (L2)	254.658	125.865
Area B (L3)	564.768	279.138
Area C (LS6)	30.708	15.178
Area D (L4)	10.984	5.429
Area E (L1)	119.760	59.192
Area F (L0, LS3, LS5, Direct Runoff) (Area F does not include septic TP loading)	117.012	57.833
Total	1097.890	542.635